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Stratigraphy of Cretaceous to Lower Pliocene sediments in the northern part of Cyprus based on comparative $^{87}Sr/^{86}Sr$ isotopic, nannofossil and planktonic foraminiferal dating

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Abstract – New age data from Sr isotope analysis and both planktonic foraminifera and nannofossils are presented and discussed here for the Upper Eocene–Upper Miocene sedimentary rocks of the Değirmenlik (Kythrea) Group. New dating is also given of some Cretaceous and Pliocene sediments. In a revised stratigraphy the Değirmenlik (Kythrea) Group is divided into ten formations. Different Upper Miocene formations are developed to the north and south of a regionally important, E–W-trending syn-sedimentary fault. The samples were dated wherever possible by three independent methods, namely utilizing Sr isotopes, calcareous nannofossils and planktonic foraminifera. Some of the Sr isotopic dates are incompatible with the nannofossil and/or the planktonic foraminiferal dates. This is mainly due to reworking within gravity-deposited or current-affected sediments. When combined, the reliable age data allow an overall biostratigraphy and chronology to be erected. Several of the boundaries of previously defined formations are revised. Sr data that are incompatible with well-constrained biostratigraphical ages are commonly of Early Miocene age. This is attributed to a regional uplift event located to the east of Cyprus, specifically the collision of the Anatolian (Eurasian) and Arabian (African) plates during Early Miocene time. This study, therefore, demonstrates that analytically sound Sr isotopic ages can yield geologically misleading ages, particularly where extensive sediment reworking has occurred. Convincing ages are obtained when isotopic dating is combined with as many forms of biostratigraphical dating as possible, and this may also reveal previously unsuspected geological events (e.g. tectonic uplift or current activity).

Keywords: north Cyprus, biostratigraphy, Sr dating, nannofossils, planktonic foraminifera, sediments, Neogene.

1. Introduction

The purpose of this paper is to present an integrated stratigraphy and chronology, based on $^{87}Sr/^{86}Sr$ isotopic, nannofossil and planktonic foraminiferal dating of Cretaceous to Pliocene sedimentary rocks exposed in the Girne (Kyrenia) Range (Fig. 1). A realistic stratigraphy of these sedimentary rocks is a prerequisite for an understanding of the sedimentary and tectonic development of Cyprus in its Eastern Mediterranean regional context. The tectono-stratigraphy of the Girne (Kyrenia) Range is characterized by several mega-sequences bounded by unconformities, of which the Upper Eocene to Upper Miocene Değirmenlik (Kythrea) Group is the focus of this paper. The present work offers an excellent opportunity to compare and discuss the results of dating using three independent techniques, with some interesting implications for studies of comparable geological settings elsewhere.

Biostratigraphical determinations of the Upper Eocene to Lower Miocene successions in the Girne (Kyrenia) Range are challenging for several reasons. First, the range is nearly 200 km long and may thus encompass considerable facies variation. Also, the exposures along the southern front of the range constitute a thrust belt and thus no complete successions exist for sampling. The succession along the northern flank of the range is relatively intact but the outcrop is variable and not complete in any one section. Also, the sediments include terrigenous turbidites in which planktonic foraminifera are typically sparse, variably preserved and were subject to reworking. On the other hand, there are also pelagic and hemipelagic intervals that contain abundant well-preserved microfossils, and

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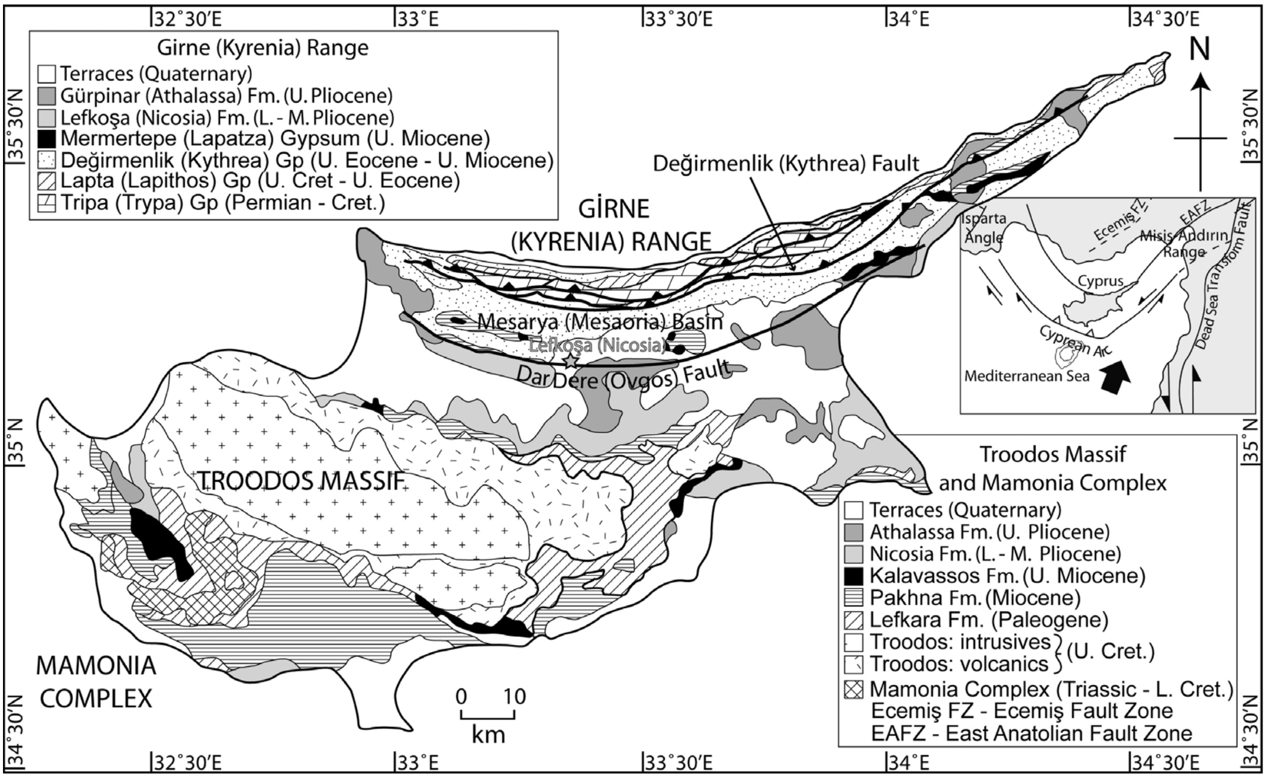

Figure 1. Simplified geological map of Cyprus indicating the Girne (Kyrenia) Range, the Troodos Massif and the Mesarya (Mesaoria) Basin. Note also the main fault lineaments in the field area, the Değirmenlik (Kythrea) Fault and the Dar Dere (Ovgos) Fault. Inset: simplified tectonic sketch map of the Eastern Mediterranean region including regionally important lineaments, namely the Eastern Anatolian Fault Zone (EAFZ), the Dead Sea Transform Fault Zone and the Ecemiş Fault Zone (Ecemiş FZ).

these are well suited to dating using a combination of techniques.

1.a. Objectives of this study

Some existing biochronological studies utilize nearly ideal sedimentary successions, for example carefully selected oceanic boreholes or reference sections on land. The combined application of several different techniques such as nannofossil and planktonic foraminiferal dating and Sr isotopic dating can provide a high-resolution biochronology, especially if large numbers of samples are used. In contrast, the main aim of this study is to provide a biochronological framework for the sedimentary and structural development of a thrust belt exposed on land. The commonly used method of detailed dating of a reference section is not applicable in this case because no such single section exists. In addition, little or no useful dating can be achieved for very coarse-grained conglomeratic intervals and thick sand turbidites that contain few, if any, microfossils. For these reasons we collected samples from suitable lithologies, especially fine-grained calcareous facies. These come from available sections along the length of the Girne (Kyrenia) Range on both its northern and southern flanks (Fig. 2).

In some sections samples were collected to allow comparison and integration with previous dating work, while in others the sampling was mainly to determine the lithological formation into which individual samples should be placed. In some cases, the sections studied and dated are in close proximity to those reported by Baroz (1979), while others are new. We are thus able to make a detailed comparison of previous and new results from planktonic foraminiferal dating and to supplement these with new data from nannofossil and Sr isotope dating.

Wherever possible, the successions that were sampled for dating were logged in detail. However, it was also important to date some samples from poorly exposed successions or structurally complex intervals where no logging was possible. In practice, the sampling was successful in allowing us to establish a lithological and temporal correlation that is applicable to the range as a whole.

Previous age determinations of the sedimentary rocks of the Girne (Kyrenia) Range mainly utilized planktonic foraminifera (Baroz & Bizon, 1974; Baroz, 1979; Hakyemez *et al*. 2000; Hakyemez & Özkan-Altıner, 2007). These earlier results are summarized here and tabulated in the online Supplementary Material available at http://journals.cambridge.org/geo. More recently, Hakyemez *et al*. (2000) identified planktonic foraminifera in each of the formations of the Girne (Kyrenia) Range, as also tabulated in the online Supplementary Material. However, locality information is not available, limiting the value of these data.

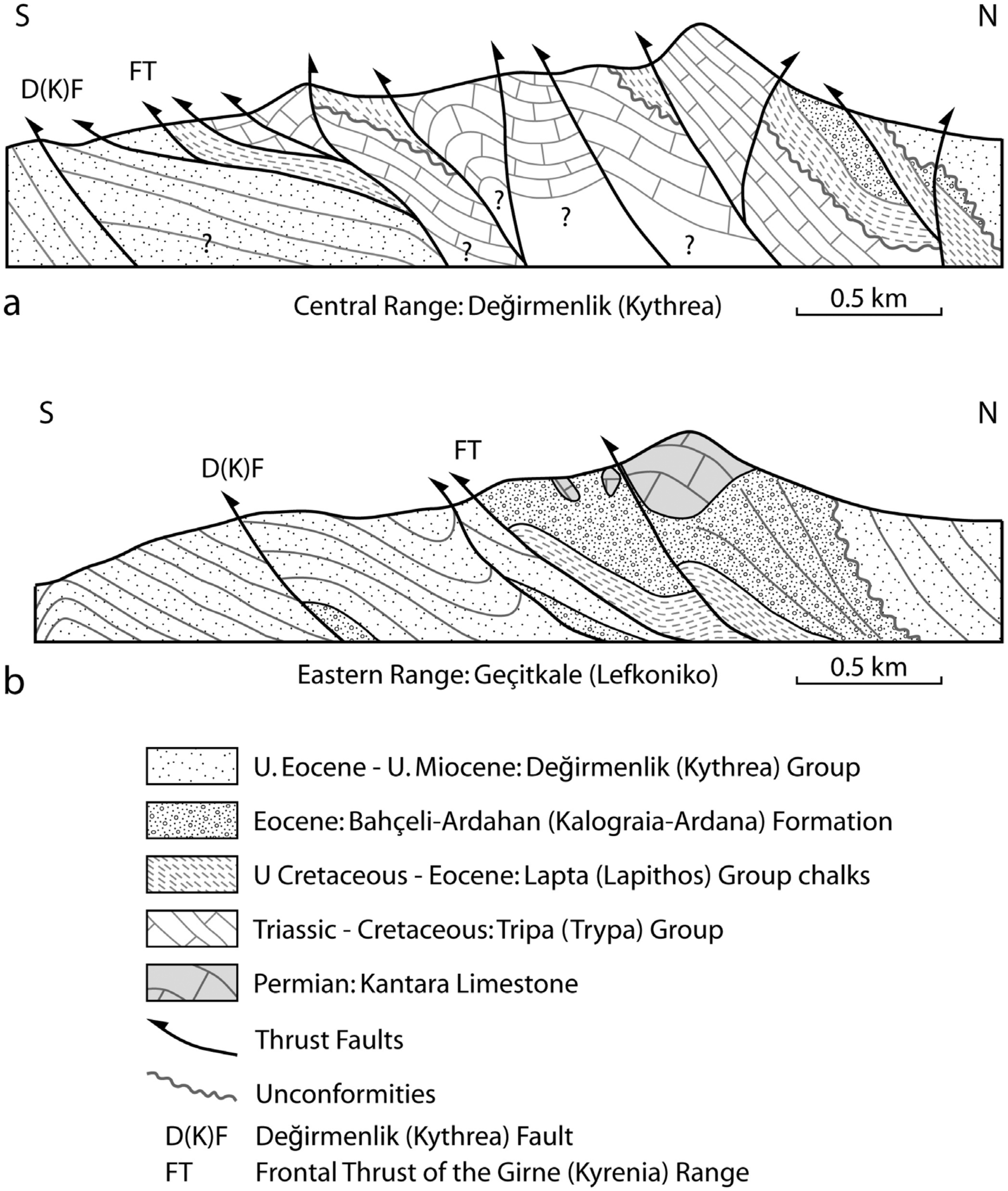

Figure 2. Simplified cross-sections of the Girne (Kyrenia) Range. (a) Western/central Girne (Kyrenia) Range; (b) eastern range. In contrast to further west, the eastern part of the range lacks an axial zone of Mesozoic platform carbonates, while sedimentary melange ('olistostromes') of the Eocene Bahçeli–Ardahan (Kalograia–Ardana) Formation is extensively exposed beneath the Upper Eocene–Upper Miocene Değirmenlik (Kythrea) Group. Modified from Baroz (1979) and Robertson & Woodcock (1986). The sections demonstrate the difficulty in sampling long intact sedimentary successions within this thrust belt.

1.b. Biostratigraphical and biochronological considerations

Age estimates from biostratigraphy are typically accurate to within $\sim\pm0.5$–4.0 Ma (e.g. Miller *et al.* 1991). Biostratigraphic resolution may be complicated by the presence of variable taxa in local sequences and by diachronous, or geographically restricted, ranges (Miller *et al.* 1988, 1991). Only in favourable instances can biostratigraphic correlations provide a resolution better than ±0.5 Ma.

To achieve consistency, the age ranges of the biomarkers given here utilize the well-known magnetochronology of Cande & Kent (1995) and the compatible biochronology of Berggren *et al.* (1995). Orbitally tuned biochronology is increasingly used but this is not available for the Sr isotopic chronology. In addition, an orbitally tuned biochronology has yet to be accepted for the Palaeogene–Neogene time interval as a whole that is considered here.

The existing lithostratigraphy was largely devised by Baroz (1979) in conjunction with mapping of much of the Girne (Kyrenia) Range. The original formation names utilized the Greek names of local villages or geographical features. Since then these names have been replaced by Turkish names. Recently, the Minerals Research and Exploration Institute (MTA) mapped the whole of the Girne (Kyrenia) Range and produced a summary report that includes new biostratigraphic data, mainly for planktonic foraminifera (Hakyemez *et al.* 2000). A copy of the report (in Turkish) has been lodged with the library of the Geological Society of London to allow easy access by any interested reader. Most of the previous formation names have been simply translated into Turkish, whereas several existing formations were assigned new type sections. Two additional Miocene formations were also erected. During this work, these two new formations were found to be valid and so are retained here.

Hakyemez *et al.* (2000) erected an additional long-ranging formation (Kozan Formation), of inferred Mid–Late Miocene age, exclusively in the west of the range (G. McCay, unpub. Ph.D. thesis, Univ. Edinburgh, 2010). Upper Miocene formations defined in the eastern and central areas of the range were believed not to be recognizable in the west of the range. However, during this work, lateral equivalents of all of the other Upper Miocene formations were found to exist in the west of the range, such that the Kozan Formation is considered to be redundant and so is not used here.

To ensure maximum clarity we give the Turkish stratigraphical name, followed by the equivalent Greek name. We also give both the Turkish and the Greek names for the settlements and the geographical features mentioned in the text. The English name Kyrenia Range (Girne in Turkish) is also known as the Beşparmak Dağları in Turkish and the Pentadactylos Oros in Greek (both meaning five-fingered mountain).

The stratigraphy used here is shown in Figure 3. Below we will discuss the key lithological features of each of the formations sampled, mainly based on previous studies by Weiler (1969, 1970), Ducloz (1972), Baroz & Bizon (1974), Baroz (1979), Robertson & Woodcock (1986) and Yetiş *et al.* (1995), combined with the results of this study (G. McCay, unpub. Ph.D. thesis, Univ. Edinburgh, 2010). The locations of the sedimentary successions that were sampled for dating are shown in Figure 4.

The Sr isotopic analysis was carried out on samples of picked and cleaned planktonic foraminifera using a previously described method (Flecker *et al.* 1998; Flecker & Ellam, 1999; Boulton *et al.* 2007). The planktonic foraminifera that were used for the Sr analysis are commonly abraded making identification difficult. However, these are not visibly recrystallized so they can be reliably used for Sr dating (see Fig. 5). Full details of the preparation, analytical methods and data reduction, including the analytical and calculated errors (here termed combined error) are given in the online Supplementary Material available at http://journals.cambridge.org/geo. The results of the Sr dating are listed in Figure 6 and Table 1.

The planktonic foraminifera and nannofossils were prepared using standard methods (e.g. Armstrong & Brasier, 2005), as explained in McCay (unpub. Ph.D. thesis, Univ. Edinburgh, 2010). Some samples contain a rich, well-preserved nannofossil flora; others contain only sparse, or poorly preserved nannofossils, while a few samples are barren. The selected age-diagnostic nannofossil taxa that were utilized during this work and the resulting inferred ages are shown in Figure 7. This figure also indicates the key planktonic foraminiferal age-marker taxa that were identified during this work. The planktonic foraminifera that were identified are listed in full in the online Supplementary Material utilizing up-to-date taxonomic nomenclature (e.g. Wade *et al.* 2011).

The ages obtained by the different methods are compiled in Table 2. Ideally a complete set of nannofossil, planktonic foraminiferal and Sr dating results should be available for each sample and this ideally should give compatible (within-error) results. However, the commonly sparse or abraded nature of the planktonic foraminifera means that only rather general age ranges could be assigned in some cases. Table 3 shows the maximum and minimum possible ages for each sample as determined by the Sr dating (i.e. from the combined error range) and by the planktonic foraminiferal and nannofossil dating (based on the chronology of Cande & Kent, 1995 and Berggren *et al.* 1995). In some cases the Sr dates are incompatible with the planktonic foraminiferal age data, the nannofossil age data, or both. Reasons for possible age discrepancies are mentioned for the relevant samples below and are considered further in Section 4. In such cases the most likely age is estimated using all of the available evidence including the ages of other samples from the same logged succession and the location with respect to regional unconformities of known age (e.g. Messinian emergence). In many cases the nannofossils yield more precise ages than the planktonic foraminifera. However, in several cases the planktonic foraminifera give geologically more realistic ages than the nannofossils. Because the samples are from different parts of a number of measured sections and from specific localities (spot samples) it is essential to consider the age results sample-by-sample for each formation and then extract the overall most credible age results.

2. Lithostratigraphy and biostratigraphy

A composite sedimentary log of the Upper Eocene–Upper Miocene sediments of the successions exposed north and south of the Girne (Kyrenia) Range together with corresponding logged intervals is shown in

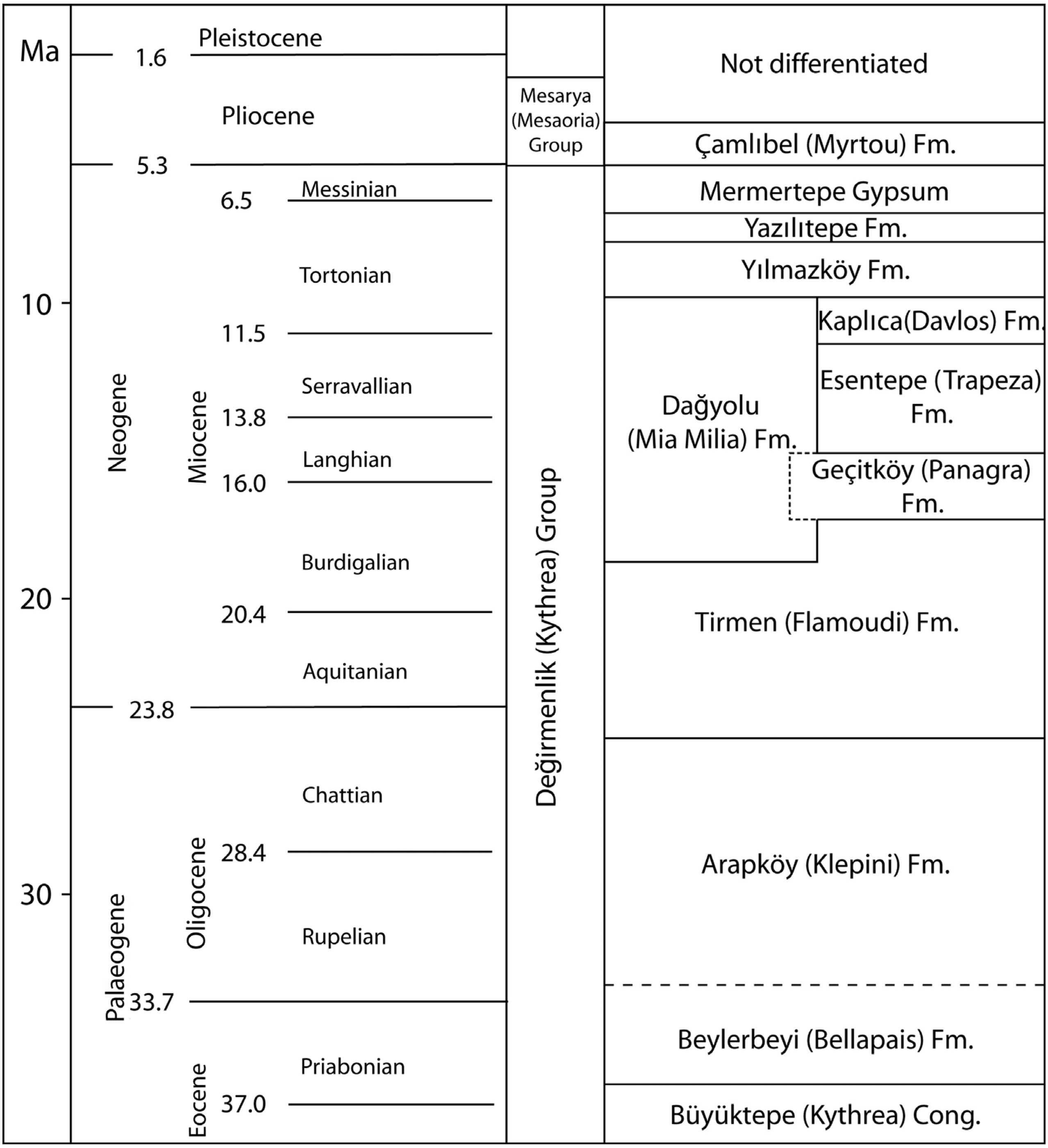

Figure 3. Stratigraphical nomenclatures for the Upper Eocene–Upper Miocene sediments in the northern part of Cyprus. This lithostratigraphy is based on a combination of Baroz (1979), Hakyemez *et al*. (2000) and this study. Previous stratigraphies are shown in the online Supplementary Material available at http://journals.cambridge.org/geo. The time scale is that of Cande & Kent (1995).

Figures 8, 9 and 10. Where samples were collected from logged sections their positions are indicated on the relevant figures. The GPS locations of additional spot samples are indicated in the text and further details are given in McCay (unpub. Ph.D. thesis, Univ. Edinburgh, 2010). Further information on the facies, petrography, mineralogy and depositional environments of the sedimentary rocks are given elsewhere (McCay & Robertson, 2012*a*).

2.a. Cretaceous undefined unit

One sample (GAM 251 – GPS: 0600791, 3929804) was collected from a thrust-imbricated sequence of sandstone turbidites and marls in the eastern part of the Girne (Kyrenia) Range, near Balalan (Platanisso). An age of 108.76 Ma (error range 113.38–108.18 Ma; i.e. Aptian–Albian) was obtained by the Sr analysis. The nannofossil assemblage yielded a Maastrichtian

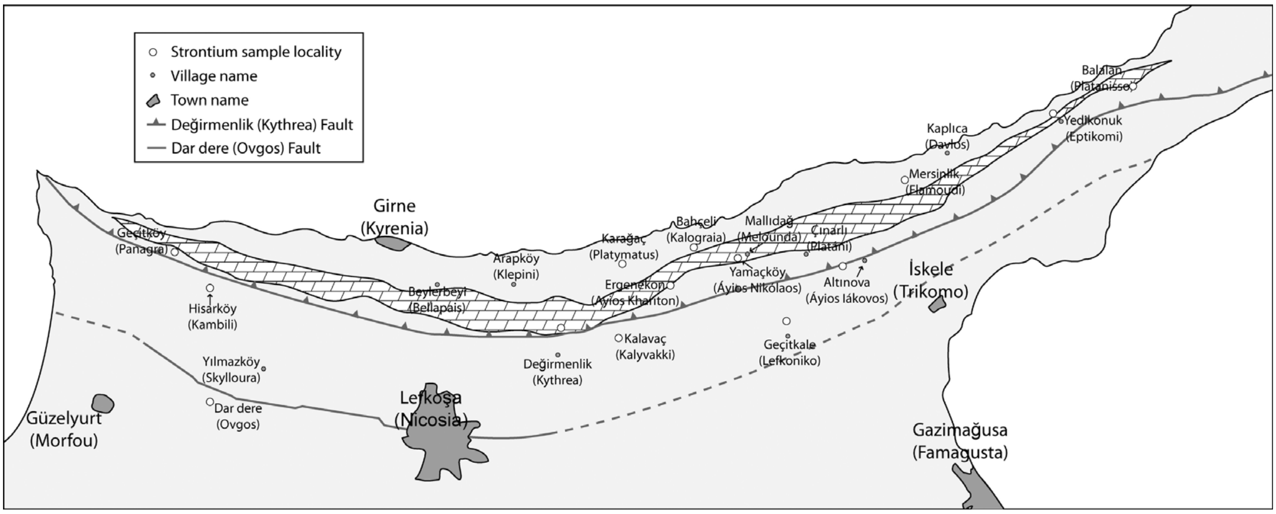

Figure 4. Sample localities for the Sr and micropalaeontological dating. See text for explanation.

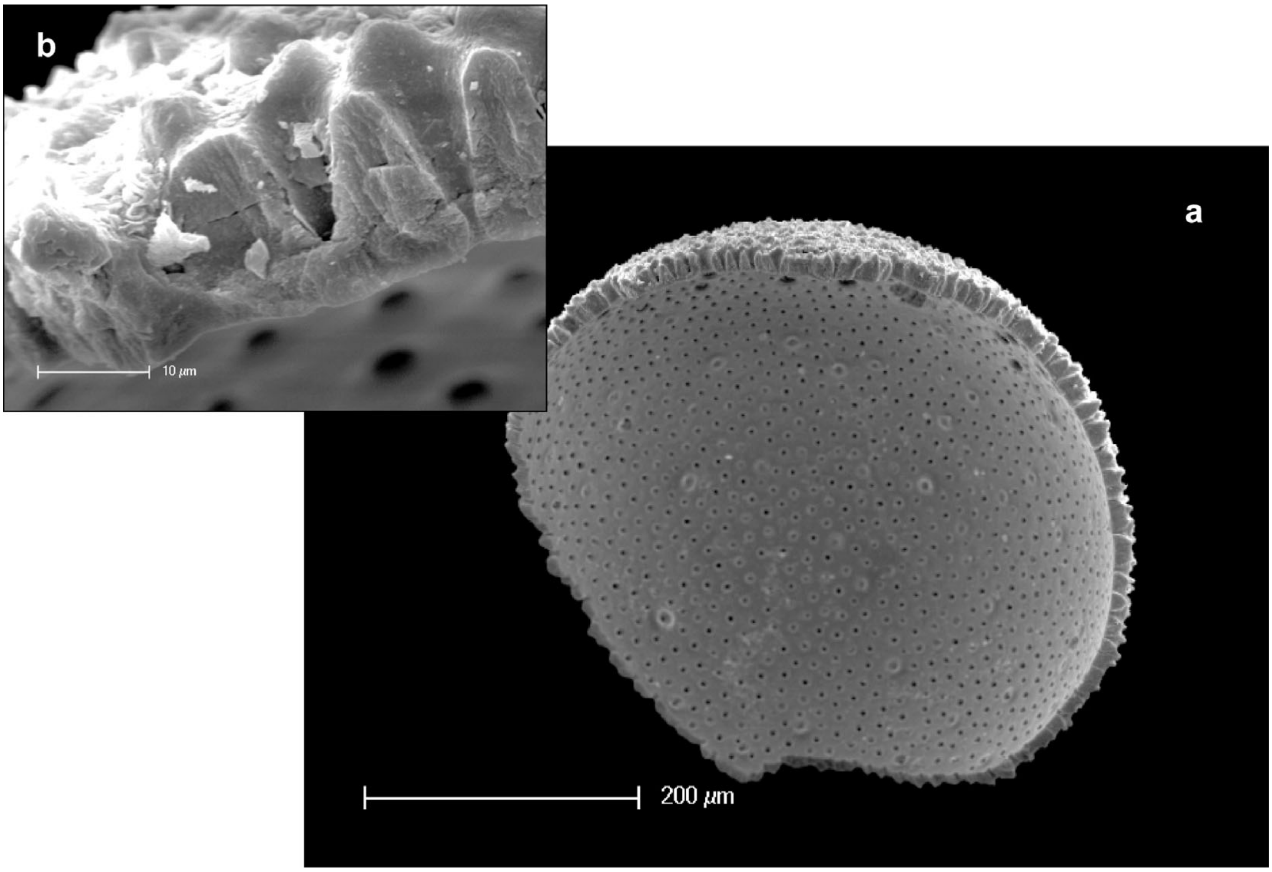

Figure 5. Scanning electron micrographs showing planktonic foraminifer preservation. (a) Specimen of *Orbulina universa* with no infilling and well-preserved internal features; (b) higher magnification view (inset). Close examination of the test indicates little or no visible recrystallization.

age (Table 2). This sample also yielded a definite Late Cretaceous (Campanian–Maastrichtian) age using planktonic foraminifera including *Globotruncana ventricosa*. The Late Cretaceous age has, therefore, to be accepted in preference to the Sr age, as both biostratigraphic results corroborate this later age.

This is the first reported evidence of Upper Cretaceous siliciclastic turbidites and pelagic carbonates in the eastern part of the Girne (Kyrenia) Range. Comparable sediments are known from the western and central parts of the Girne (Kyrenia) Range (Robertson, Taslı & İnan, 2012). In general, the Upper Cretaceous sediments accumulated in a deep-water basin, with the terrigenous sediment being derived from the present area of Turkey to the north or from its southward extension beneath the Cilicia Basin that separated Cyprus from Turkey (McCay & Robertson, 2012*a*).

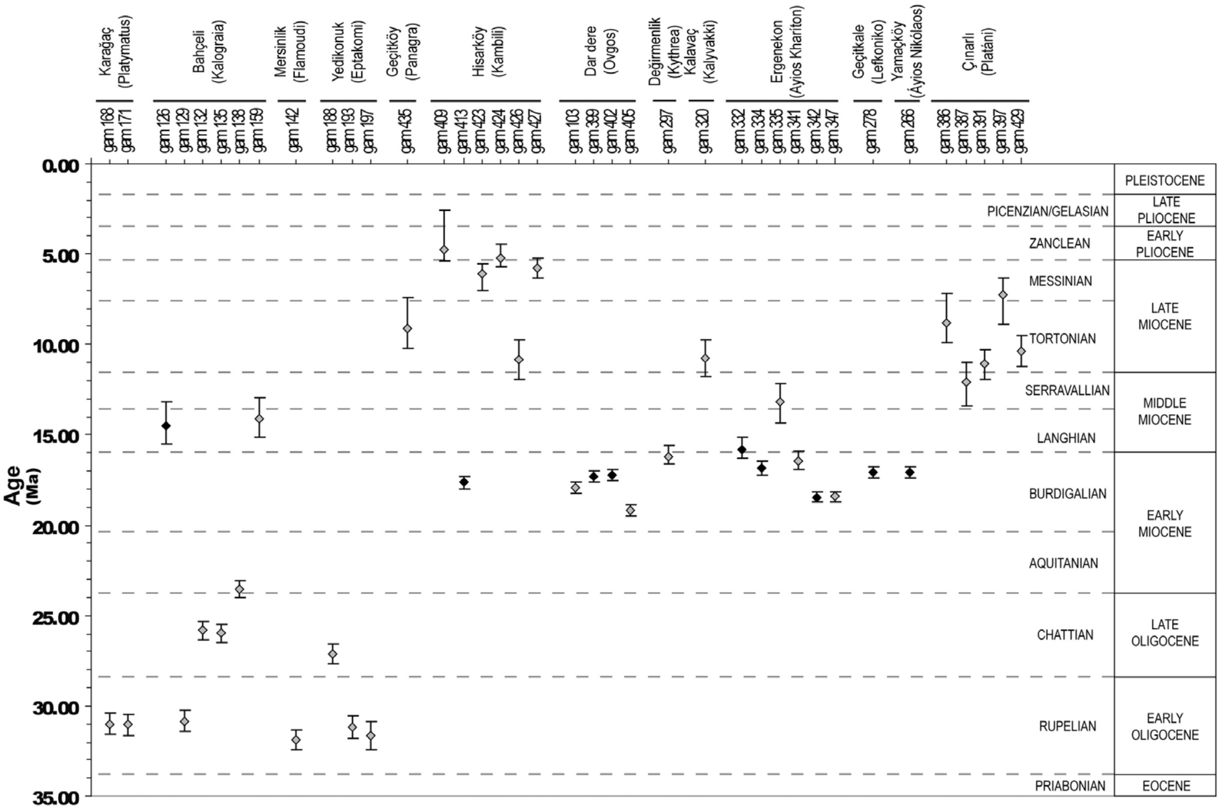

Figure 6. Results of $^{87}Sr/^{86}Sr$ analysis including error bars (calculated from empirical and analytical errors) and stages of deposition, plotted against the stages of sediment deposition. Sample numbers are arranged by locality (see Fig. 4). Black diamonds indicate samples that are found to be inconsistent with well-constrained biostratigraphic ages (see Tables 2 & 3). Note: owing to scaling, the data point for one sample (GAM 251) is not displayed to allow the error bars of other samples to be seen clearly. It should be noted that for the Sr isotopic dating method to work it is necessary to know the approximate age of the rocks in advance, a condition that is met in this case by the available biostratigraphical studies.

These Cretaceous sediments experienced severe thrusting and folding during the Late Cretaceous and the Eocene periods, which did not affect any of the younger, Upper Eocene–Pliocene sediments discussed below.

2.b. Beylerbeyi (Bellapais) Formation, including Büyüktepe (Kythrea) Conglomerate: conglomeratic units and fine- to medium-grained sandstones

We now focus on the successions in the Girne (Kyrenia) Range that accumulated following an important episode of southward thrusting during Early–Middle Eocene time (Baroz 1979; Robertson & Woodcock, 1986; Robertson, Taslı & İnan, 2012). The basal sediments above the deformed lithologies were originally named by Baroz (1979) as the Kythrea Conglomerate and the Bellapais Formation, later translated into Turkish as the Büyüktepe Conglomerate and the Beylerbeyi Formation (Hakyemez *et al*. 2000). The Büyüktepe (Kythrea) Conglomerate is treated as an informal unit of the transitionally overlying Beylerbeyi (Bellapais) Formation. The formation is named after Beylerbeyi (Bellapais) village, 5 km southeast of Girne (Kyrenia). The type locality is in a tributary of the Arma stream, ~640 m east of Beylerbeyi (Bellapais) village (Ducloz, 1972). The Beylerbeyi (Bellapais) Formation is extensively exposed along the northern and southern margins of the range and in the Karpaz (Karpas) Peninsula in the extreme northeast of the island. Its regional thickness is estimated as up to 400 m.

The base of the Büyüktepe (Kythrea) Conglomerate unit is marked by an angular unconformity with the underlying Tripa (Trypa) Group and the Lapta (Lapithos) Group (Moore, 1960; Baroz, 1979; Hakyemez *et al*. 2000). At its base the conglomeratic unit (50–70 m thick) mainly consists of channelized, parallel and cross-bedded, clast-supported conglomerates and coarse sandstones. These form fining-upward cycles, each up to several metres thick. The conglomerates comprise poorly to moderately sorted, mainly well-rounded clasts, 15–20 cm in size, including all of the lithologies exposed in the underlying deformed units of the Girne (Kyrenia) Range.

Above the basal conglomerate the Beylerbeyi (Bellapais) Formation is dominated by coarse- to medium-grained lithic sandstones that are dark brown, yellow or khaki in colour, with light brown grey mudstone interbeds. Sedimentary features include sole structures (e.g. flutes and load casts), graded bedding and trace fossils on upper bed surfaces. The sediments are composed of up to 90 % extra-basinal material, mainly igneous-derived material.

Table 1. Results of $^{87}Sr/^{86}Sr$ analysis

Sample No	$^{87}Sr/^{86}Sr$ ratio	2 Standard Error (2SE)	Age (Ma)	Age range (error from empirical data)	Age range (error including 2SE)	Age of sediment
North						
GAM 168	0.707939	0.000020	31.02	30.94–31.10	30.43–31.59	Rupelian
GAM 171	0.707938	0.000020	31.04	30.96–31.12	30.46–31.61	Rupelian
GAM 126	0.708787	0.000023	14.52	14.39–14.66	13.19–15.48	Langhian
GAM 129	0.707946	0.000020	30.85	30.76–30.93	30.24–31.42	Rupelian
GAM 132	0.708148	0.000021	25.80	25.73–25.87	25.33–26.32	Chattian
GAM 135	0.708139	0.000021	25.99	25.92–26.06	25.50–26.51	Chattian
GAM 138	0.708267	0.000020	23.54	23.48–23.60	23.08–23.99	Chattian
GAM 159	0.708795	0.000020	14.14	14.00–14.28	12.94–15.15	Serravallian
GAM 142	0.707904	0.000020	31.88	31.79–31.96	31.30–32.43	Rupelian
GAM 188	0.708088	0.000020	27.10	27.02–27.18	26.58–27.65	Chattian
GAM 193	0.707932	0.000023	31.19	31.11–31.27	30.53–31.84	Rupelian
GAM 197	0.707914	0.000028	31.63	31.54–31.71	30.86–32.39	Rupelian
South						
GAM 435	0.708917	0.000023	9.14	8.93–9.34	7.42–10.19	Tortonian
GAM 409	0.709046	0.000020	4.72	4.59–4.83	2.57–5.35	Zanclean
GAM 413	0.708633	0.000021	17.65	17.60–17.69	17.33–17.97	Burdigalian
GAM 423	0.708981	0.000027	6.10	6.03–6.17	5.57–7.05	Messinian
GAM 424	0.709028	0.000021	5.24	5.17–5.31	4.42–5.70	Zanclean
GAM 426	0.708873	0.000027	10.80	10.70–10.91	9.71–11.89	Tortonian
GAM 427	0.709001	0.000026	5.74	5.69–5.79	5.19–6.31	Messinian
GAM 103	0.708609	0.000020	17.96	17.92–18.01	17.65–18.26	Burdigalian
GAM 399	0.708659	0.000021	17.31	17.27–17.35	16.96–17.62	Burdigalian
GAM 402	0.708664	0.000020	17.24	17.20–17.28	16.90–17.55	Burdigalian
GAM 405	0.708509	0.000020	19.18	19.13–19.23	18.89–19.51	Burdigalian
GAM 297	0.708730	0.000023	16.20	16.14–16.26	15.61–16.64	Burdigalian
GAM 320	0.708874	0.000024	10.77	10.67–10.88	9.78–11.74	Tortonian
GAM 332	0.708749	0.000020	15.79	15.72–15.87	15.14–16.27	Langhian
GAM 334	0.708691	0.000020	16.84	16.79–16.89	16.48–17.19	Burdigalian
GAM 335	0.708813	0.000020	13.18	13.03–13.34	12.17–14.38	Serravallian
GAM 341	0.708714	0.000027	16.48	16.43–16.52	15.91–16.95	Burdigalian
GAM 342	0.708571	0.000020	18.44	18.40–18.48	18.15–18.71	Burdigalian
GAM 347	0.708573	0.000020	18.41	18.37–18.45	18.13–18.69	Burdigalian
GAM 278	0.708675	0.000020	17.08	17.04–17.13	16.73–17.40	Burdigalian
GAM 266	0.708675	0.000020	17.08	17.04–17.13	16.73–17.40	Burdigalian
GAM 386	0.708923	0.000021	8.82	8.56–9.05	7.21–9.90	Tortonian
GAM 387	0.708838	0.000026	12.09	11.97–12.20	11.00–13.39	Serravallian
GAM 391	0.708865	0.000020	11.08	10.97–11.19	10.27–11.93	Tortonian
GAM 397	0.708947	0.000021	7.22	7.08–7.41	6.35–8.87	Messinian
GAM 429	0.708885	0.000020	10.40	10.27–10.51	9.51–11.19	Tortonian
GAM 251	0.707297	0.000020	108.79	108.49–109.35	108.18–113.38	Cretaceous

The age of the sample was calculated using the LOWESS look-up table of Howarth & McArthur (1997). Two age ranges are given: the first is the uncertainty of the sea-water curve for the given Sr ratio, while the second lists the analytical uncertainty incorporated into the error related to the sea-water curve. This second error calculation gives the true (total) error measurement, which must be considered when assigning an absolute age. Details of the sample preparation, data reduction and calculation of errors are given in the online Supplementary Material available at http://journals.cambridge.org/geo and in McCay (unpub. Ph.D. thesis, Univ. Edinburgh, 2010). Samples from the northern flank of the Girne (Kyrenia) Range are listed first and then those on the southern flank.

The upper boundary is commonly gradational with the overlying Arapköy (Klepini) Formation and is generally marked by the last occurrence of medium to coarse sandy beds, which are followed by repetitive packages of siltstone or claystone (Baroz, 1979).

2.b.1. *Dating evidence*

The coarse, granular, redeposited nature of the Beylerbeyi (Bellapais) Formation is generally unfavourable to the preservation of microfossils. However, the reported presence of *Turborotalia cerroazulensis* is suggestive of a Late Eocene age (Baroz & Bizon, 1974; Baroz, 1979). There are also numerous fossiliferous clasts derived from Middle Eocene and older units.

The Beylerbeyi (Bellapais) Formation includes mudstones that have yielded planktonic foraminifera of Early Oligocene (Rupelian) age (Baroz & Bizon, 1974; Robertson & Woodcock, 1986; Yetiş *et al*. 1995; Hakyemez *et al*. 2000). In the central part of the Girne (Kyrenia) Range the upper limits of the formation have been determined as Late Oligocene based on the occurrence of the species *Paragloborotalia opima* (Chattian) (Baroz & Bizon, 1974; Baroz, 1979).

During this work the Beylerbeyi (Bellapais) Formation was sampled and dated in several sections (Fig. 8a, b), as follows.

One sample (GAM 168 – GPS: 0545143, 3906433) was collected from a thick bed of silty marl within the well-exposed transition between the Büyüktepe (Kythrea) Conglomerate unit and the finer grained facies of the Beylerbeyi (Bellapais) Formation, near Karağaç (Platymatus) village (Fig. 4). Sr analysis (Fig. 6; Tables 2, 3) yields an age of 31.02 Ma (31.59–30.43 Ma; Rupelian), in agreement with the previously reported biostratigraphic age (Baroz, 1979).

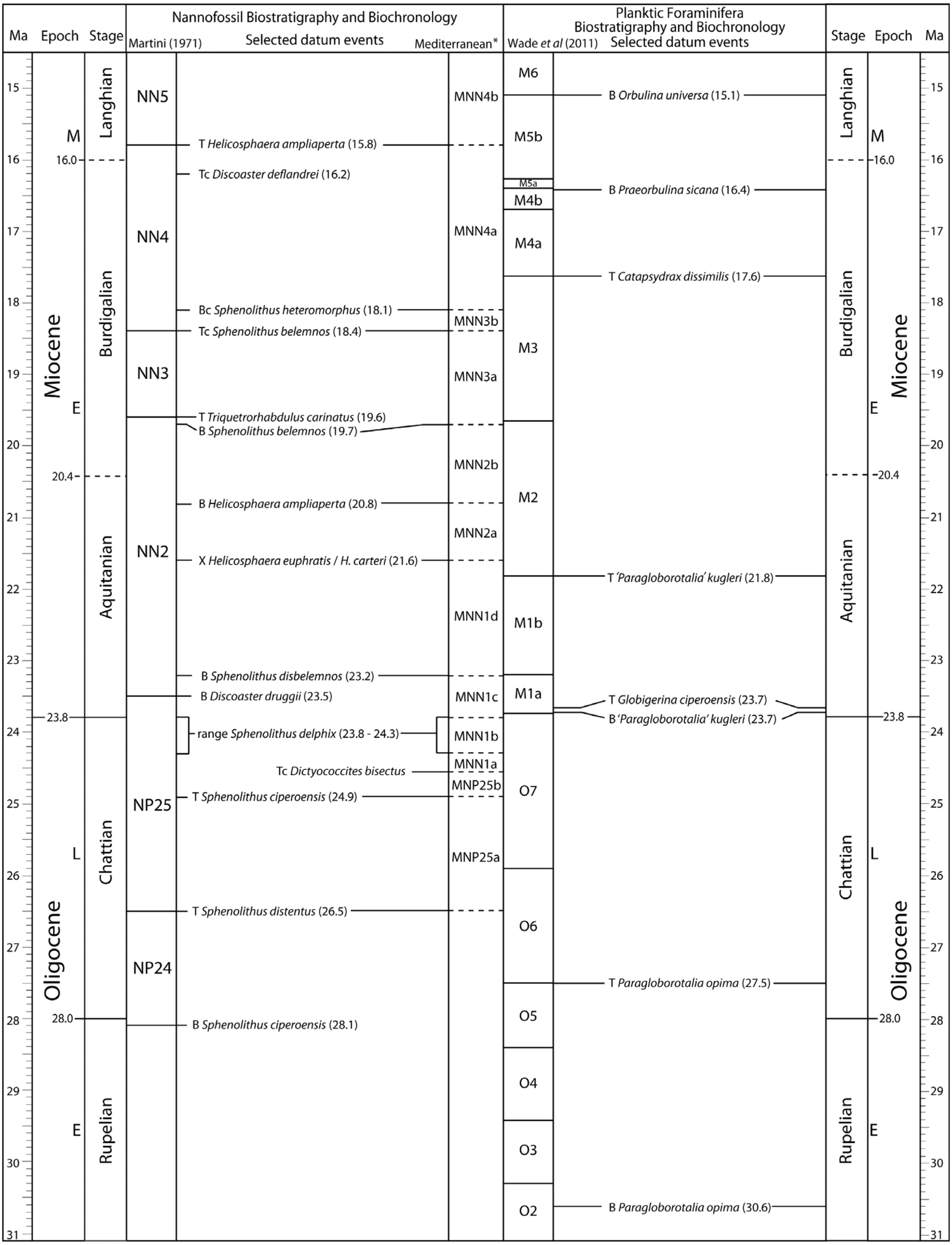

Figure 7. Results of nannofossil and planktonic foraminiferal biostratigraphy and biochronology that were obtained during this work. (a) Early Oligocene–Middle Miocene. The nannofossil biochronology of Raffi *et al*. (2003), used here, is well suited to the Mediterranean (developed from e.g. Martini, 1971). The planktonic foraminiferal results utilize the up-to-date nomenclature of Wade *et al*. (2011). The time scale is that of Cande & Kent (1995) to allow consistency with the Sr data. Note: dashed lines show inferred correlations of the global nannofossil biochronology with that for the Mediterranean.

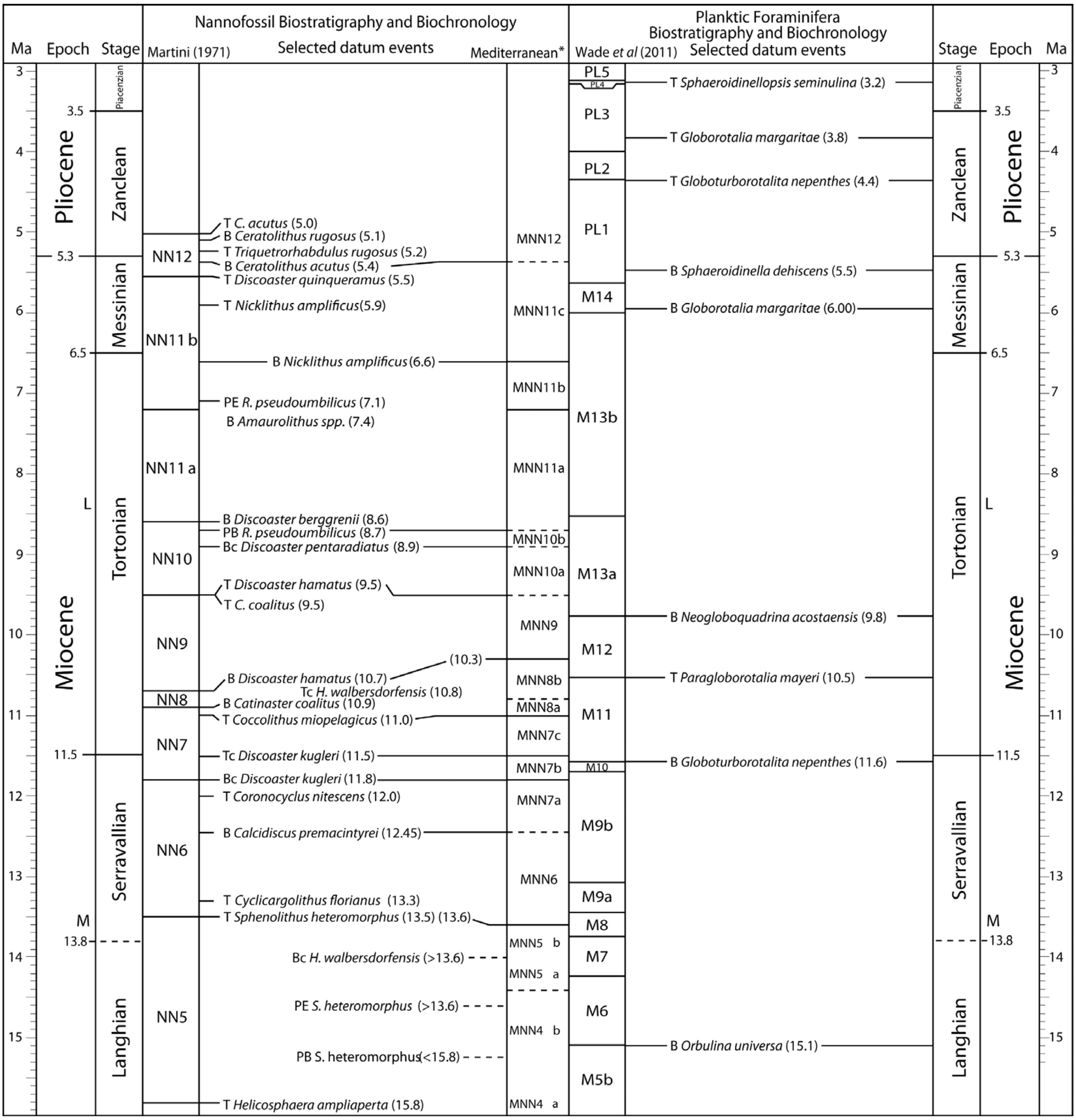

Figure 7. (continued) Results of nannofossil and planktonic foraminiferal biostratigraphy and biochronology that were obtained during this work. (b) Middle Miocene–Pliocene.

Nannofossils and planktonic foraminifera from this sample indicate an Oligocene age (Table 2).

Another sample (GAM 171 – GPS: 0544931, 3906565) was collected from stratigraphically higher thin-bedded, fine-grained sandstones that are intercalated with siltstone and marl. Sr analysis yields an age of 31.04 Ma (31.61–30.46 Ma; Rupelian). The nannofossils indicate only a generic Oligocene age (Table 2). Sample GAM 171 was collected from a stratigraphically higher position than sample GAM 168. However, the Sr dating suggests that GAM 171 is older. This inconsistency is not considered significant because the error bars of the two Sr dating results overlap. A Rupelian (Late Oligocene) age is therefore accepted for both samples.

Sample GAM 142 (GPS: 0578073, 3916043) was collected near Mersinlik (Flamoudi) village (Fig. 4) from a claystone bed close to the base of the Beylerbeyi (Bellapais) Formation. This was previously dated as Oligocene using planktonic foraminifera (Baroz, 1979; Hakyemez *et al.* 2000). In agreement, the Sr age of 31.88 Ma (32.43–31.30 Ma) indicates a Rupelian–Chattian age. The nannofossil age data for GAM 142 indicate an age of ~30 Ma. This, although younger than the Sr age, is still within the Early Oligocene. A further sample (GAM 197 – GPS: 0591843, 3923167) was taken from near the base of the Beylerbeyi (Bellapais) Formation near Yedikonuk (Eptakomi) village (Figs 4, 8c). Sr analysis (Fig. 6) yields an age of 31.63 Ma (30.86–32.39 Ma;

Table 2. Comparison of the ages inferred for samples from the northern flank of the Girne (Kyrenia) Range using different methods

Location	Sample No.	Predicted age of sediment from previous work e.g. Baroz (1979)	Age of sediment derived from planktonic foraminifera dating carried out during this study	Age of sediment derived from nannofossil dating during this study	Sr Age (Ma)	Age of sediment derived from Sr
North of Girne (Kyrenia) Range						
Karağaç (Platymatus)	GAM 168	Rupelian/Chattian	**Oligocene**	**Oligocene**	**31.02**	**Rupelian**
Karağaç (Platymatus)	GAM 171	Chattian/Aquitanian		**Generic Oligocene**	**31.04**	**Rupelian**
Bahçeli (Kalograia)	GAM 126	Rupelian/Chattian	**Oligocene**		14.52	Langhian
Bahçeli (Kalograia)	GAM 129	Rupelian/Chattian			**30.85**	**Rupelian**
Bahçeli (Kalograia)	GAM 132	Rupelian/Chattian	**Oligocene**	**Late Oligocene (MNP25a)**	**25.80**	**Chattian**
Bahçeli (Kalograia)	GAM 135	Chattian/Aquitanian	**Oligocene**	**Late Oligocene (MNP25–MNN1)**	**25.99**	**Chattian**
Bahçeli (Kalograia)	GAM 138	Aquitanian/Burdigalian	Langhian	**Early Miocene (MNN1)**	**23.54**	**Aquitanian**
Bahçeli (Kalograia)	GAM 159	Serravallian	**Middle–Late Miocene**		**14.14**	**Langhian**
Bahçeli (Kalograia)	GAM 162	Tortonian	**Late Miocene–Early Pliocene (M13b–PL3)**			
Bahçeli (Kalograia)	K/10/80	Aquitanian		**Aquitanian (MNN1d–MNN2a)**		
Bahçeli (Kalograia)	K/10/82	Aquitanian		**Aquitanian (MNN1d–MNN2a)**		
Mersinlik (Flamoudi)	GAM 142	Rupelian/Chattian	**Oligocene**	**Early Oligocene (∼30 Ma)**	*31.88*	*Rupelian*
Mersinlik (Flamoudi)	K/10/75	Chattian		**Chattian (MNP25–MNN1)**		
Mersinlik (Flamoudi)	K/10/77	Chattian		**Chattian (MNP25–MNN1)**		
Mersinlik (Flamoudi)	K/10/79	Chattian		**Chattian (MNP25–MNN1)**		
Yedikonuk (Eptakomi)	GAM 188	Aquitanian	**Oligocene–Late Miocene**	**Late Oligocene (MNP25)**	*27.10*	*Chattian*
Yedikonuk (Eptakomi)	GAM 193	Chattian/Aquitanian	**Oligocene**	**Late Oligocene (MNP25)**	*31.19*	*Rupelian*
Yedikonuk (Eptakomi)	GAM 197	Rupelian/Chattian			31.63	Rupelian
South of Girne (Kyrenia) Range						
Geçitköy (Panagra)	GAM 435	Aquitanian/Burdigalian	**Late Miocene–Late Pliocene (M11–PL1)**	**Serravallian–Tortonian (MNN8a–MNN8b)**	**9.14**	**Tortonian**
Geçitköy (Panagra)	GAM 434	Aquitanian/Burdigalian	**Langhian**			
Geçitköy (Panagra)	GAM 433	Tortonian	**Late Miocene**			
Hisarköy (Kambili)	GAM 409	Pliocene	**Late Miocene–Early Pliocene**	**Early Pliocene (MNN12)**	***4.72***	***Zanclean***
Hisarköy (Kambili)	GAM 413	Pliocene	**Late Miocene–Early Pliocene**	**Generic Pliocene**	17.65	Burdigalian
Hisarköy (Kambili)	GAM 423	Pliocene/ Messinian	**Late Miocene–Early Pliocene**	**Early Pliocene (MNN12)**	*6.10*	*Messinian*
Hisarköy (Kambili)	GAM 424	Pliocene	**Late Miocene–Early Pliocene**	**Early Messinian (MNN11b–MNN11c)**	***5.24***	***Zanclean***
Hisarköy (Kambili)	GAM 426	Serravallian		**Tortonian (MNN11a)**	*10.80*	*Tortonian*
Hisarköy (Kambili)	GAM 427	Messinian	**Messinian–Pliocene (M14–PL2)**	**Messinian (MNN8–MNN9)**	**5.74**	**Messinian**
Dar Dere (Ovgos)	GAM 103	Eocene/Oligocene	**Middle–Late Miocene**	**Middle Miocene (∼15 Ma; MNN4–MNN5)**	**17.96**	**Burdigalian**
Dar Dere (Ovgos)	GAM 399	Eocene/Oligocene	**Middle–Late Miocene**	**Early–Middle Miocene (MNN5a)**	17.31	Burdigalian

Table 2. Continued

Location	Sample No.	Predicted age of sediment from previous work e.g. Baroz (1979)	Age of sediment derived from planktonic foraminifera dating carried out during this study	Age of sediment derived from nannofossil dating during this study	Sr Age (Ma)	Age of sediment derived from Sr
Dar Dere (Ovgos)	GAM 402	Eocene/Oligocene	**Middle–Late Miocene**	**Early–Middle Miocene (MNN5a)**	17.24	Burdigalian
Dar Dere (Ovgos)	GAM 405	Eocene/Oligocene	**late Early Miocene–early Middle Miocene**	**Early Miocene (MNN3a)**	**19.18**	**Burdigalian**
Değirmenlik (Kythrea)	GAM 297	Langhian			***16.20***	***Burdigalian***
Kalavaç (Kalyvakki)	GAM 320	Serravallian/Tortonian			**10.77**	**Tortonian**
Ergenekon (Ayios Kharíton)	GAM 332	Serravallian/Tortonian	**Late Miocene**	**Serravallian–Tortonian (MNN7c)**	15.79	Langhian
Ergenekon (Ayios Kharíton)	GAM 334	Serravallian	**Middle–Late Miocene**	**Serravallian (MNN7)**	16.84	Burdigalian
Ergenekon (Ayios Kharíton)	GAM 335	Serravallian	**Middle–Late Miocene**	**Serravallian (MNN7a)**	***13.18***	***Serravallian***
Ergenekon (Ayios Kharíton)	GAM 341	Langhian	**Middle–Late Miocene**		**16.48**	**Burdigalian**
Ergenekon (Ayios Kharíton)	GAM 342	Langhian	**Middle–Late Miocene**		18.44	Burdigalian
Ergenekon (Ayios Kharíton)	GAM 347	Serravallian/Tortonian	**late Middle Miocene–Late Pliocene**	**Langhian (MNN4a)**	*18.41*	*Burdigalian*
Geçitkale (Lefkoniko)	GAM 278	Serravallian/Tortonian	**Late Miocene–Late Pliocene (M13a–PL1)**	**Serravallian–Tortonian (MNN6–MNN7)**	17.08	Burdigalian
Yamaçköy (Áyios Nikólaos)	GAM 266	Serravallian	**Late Miocene**	**Tortonian (∼11 Ma; NN8)**	17.08	Burdigalian
Çınarlı (Platáni)	GAM 386	Tortonian			**8.82**	**Tortonian**
Çınarlı (Platáni)	GAM 387	Tortonian	**Early–Late Miocene**	**Tortonian (MNN8–MNN9)**	***12.09***	***Serravallian***
Çınarlı (Platáni)	GAM 391	Tortonian	**early Late Miocene (M13a–PL1)**	**Early Tortonian (MNN8b)**	*11.08*	*Serravallian*
Çınarlı (Platáni)	GAM 397	Tortonian	**Middle Miocene–Recent**	**Early Tortonian– Messinian (MNN7b–MNN8a)**	*7.22*	*Messinian*
Çınarlı (Platáni)	GAM 429	Tortonian	**Late Miocene–Recent**	**Serravallian–Tortonian (MNN7–MNN8)**	**10.40**	**Tortonian**
Balalan (Platanisso)	GAM 251	Burdigalian	**Campanian–Maastrichtian**	**Maastrichtian**	108.79	Albian

The first age is inferred by lithological correlation using previous biostratigraphic work (Baroz & Bizon, 1974; Baroz, 1979; Hakyemez *et al*. 2000); the second is from the new planktonic foraminiferal dating; and the third is from the new nannofossil dating. The dates derived from $^{87}Sr/^{86}Sr$ analysis in **bold** are those accepted as representative of the age of the formation following comparison with well-constrained planktonic foraminiferal and nannofossil ages for each particular sample. Ages that are within error of the predicted stage derived from previous work are in *italics* (samples for which no new well-constrained biostratigraphic data are available). Sr dates that are inconsistent with well-constrained biostratigraphic data are plain text (see also Table 3).

Rupelian). Although no biostratigraphic data are available for this sample this Sr date is in agreement with field stratigraphy and is also consistent with an Eocene to Late Oligocene age range that was previously assigned to the formation as a whole (Baroz, 1979; Hakyemez *et al*. 2000).

The Beylerbeyi (Bellapais) Formation was also sampled in several short sequences near Bahçeli (Kalograia) (Fig. 4). Two samples (GAM 129 – GPS: 0557089, 3911179 and GAM 132 – GPS: 0556978, 3911192) were collected from a local fining-upward sequence (Fig. 8a), transitional from the Beylerbeyi (Bellapais) Formation to the Arapköy (Klepini) Formation. The stratigraphically lower sample (GAM 129) gives a Sr age of 30.85 Ma (31.42–30.24 Ma; Rupelian), whereas the sample above (GAM 132) has a Sr age of 25.80 Ma (26.32–25.33 Ma; Chattian) (Fig. 6). The inferred Late Eocene – Early Oligocene age of sample GAM 129 is supported by the nannofossil assemblage in sample GAM 132 that is indicative of Biozone MNP25a (Chattian) (Table 2). The planktonic foraminiferal assemblage for GAM 132 is also indicative of an Oligocene age (Fig. 7a). The interval sampled is, therefore, likely to correspond to the top of the Beylerbeyi (Bellapais) Formation. Another sample (GAM 126 – GPS: 0556725, 3910624) was collected from a lower level of the same sequence (Fig. 8b). Sr analysis yields an age of 14.52 Ma (15.48–13.19 Ma; Langhian–Serravallian) suggesting a Langhian age (Fig. 6). In contrast, the planktonic foraminifera (e.g. *Paragloborotalia opima*, *Globoquadrina venezuelana*, *Globigerina ouachitaensis*) suggest an Oligocene age (Table 2). Unfortunately, this sample is almost barren of calcareous nannoplankton. A Langhian Sr age is inconsistent with the foraminiferal age and the previously reported Late Eocene – Late Oligocene age range of the Beylerbeyi (Bellapais) Formation (Baroz, 1979; Hakyemez *et al*. 2000) and so has to be discounted. The possible reason is that GAM 126 was the smallest sample to be analysed (~30 foraminifera specimens), with a total weight before analysis of only 0.00033 g and thus the resulting age may be inaccurate.

2.c. Arapköy (Klepini) Formation: fine-grained sandstones, siltstones and marls

Originally defined as the Klepini Formation by Baroz (1979), this stratigraphic interval was renamed the Arapköy Formation by Hakyemez *et al.* (2000). The formation is named after Arapköy (Klepini) village, 9 km ESE of Girne (Kyrenia). The type section is located along Bostan stream.

The Arapköy (Klepini) Formation is dominated by alternations of fine- to medium-grained sandstones, siltstone, hemipelagic mudrocks, organic-rich marls and planktonic foraminifera-rich limestones. The siltstones form 5–10 cm thick beds of similar composition to the thin-bedded, siltstone turbidites of the Beylerbeyi (Bellapais) Formation. Finely laminated, black organic-rich layers (sapropels), up to several centimetres thick, are found within the siltstones. These become white when oxidized making them difficult to spot in the field (Baroz, 1979). The marl and mudstone in the Arapköy (Klepini) Formation form thin beds, 1–2 cm thick with little terrigenous material. These fine-grained sediments are composed of 70 % clay, with only small amounts of quartz and mica. Planktonic foraminifera are preferentially preserved in these layers. Calcium carbonate-rich intervals are common in the upper parts of the formation. The formation crops out extensively on both the northern and southern flanks of the range, where it is estimated to be 200 m thick. The upper boundary of the formation lies within a conformable transition to the Tirmen (Flamoudi) Formation.

2.c.1. *Dating evidence*

The upper part of the Arapköy (Klepini) Formation is characterized by a lithological marker horizon of red clays, 10–20 cm thick. This was reported to belong to the Late Oligocene *Globigerina ciperoensis* Biozone (Baroz & Bizon, 1974; Baroz, 1979). Other biozones indicative of a Late Oligocene age (e.g. *Paragloborotalia opima*; Fig. 7a) also occur in the Arapköy (Klepini) Formation (Baroz & Bizon, 1974; Baroz, 1979).

Several samples were collected from the Arapköy Formation in the Bahçeli (Kalograia) area (Fig. 4). Samples GAM 135 (GPS: 0556717, 3911409) and GAM 138 (GPS: 0556290, 3911516) both occur stratigraphically above samples from the Beylerbeyi (Bellapais) Formation (GAM 129 and GAM 132), discussed above. Specifically, sample GAM 135 was collected from a marl bed stratigraphically below deposits that are lithologically similar to the Tirmen (Flamoudi) Formation. The sample collected could, therefore, represent the top of the Arapköy (Klepini) Formation. Strontium analysis of GAM 135 yielded an age of 25.99 Ma (26.51–25.50 Ma) (Fig. 6) indicating a Chattian age. This is consistent with the age derived from the planktonic foraminiferal assemblage, which indicates an Oligocene age, and also with that from the nannofossil assemblage, which is indicative of MNP25–MNN1 (Late Oligocene). These data are consistent with the previously reported age of the Arapköy (Klepini) Formation (Baroz, 1979).

Two samples (GAM 188 – GPS: 0591565, 3923492; GAM 193 – GPS: 0591817, 3923329) were collected further east, near Yedikonuk (Eptakomi) (Fig. 4). These yielded ages of 27.10 Ma (27.65–26.58 Ma; Chattian) and 31.19 Ma (31.84–30.53 Ma; Rupelian), respectively (Fig. 6). Nannofossils in sample GAM 193 yielded a Late Oligocene (MNP25) age (Table 2), while rare poorly preserved planktonic foraminifera can only be generally dated as Oligocene. The Sr age for this (GAM 193) sample is indicative of an Early Oligocene age, which is consistent with

Table 3. Comparison of the planktonic foraminiferal, calcareous nannofossil and Sr isotopic ages, calibrated with the time scales of Cande & Kent (1991) and Berggren *et al*. (1995)

	Planktonic foraminifera age		Nannofossil age					
Sample	minimum	maximum	minimum	maximum	minimum	Sr age	maximum	Consistent
GAM 168	**23.70**	**33.70**	**23.70**	**33.70**	**30.43**	**31.02**	**31.59**	**yes**
GAM 171	No Data	No Data	**23.70**	**33.70**	**30.46**	**31.04**	**31.61**	**yes**
GAM 126	23.70	33.70	No Data	No Data	13.19	14.52	15.48	no
GAM 129	No Data	No Data	No Data	No Data	30.24	30.85	31.42	?
GAM 132	**23.70**	**33.70**	**24.60**	**26.50**	**25.33**	**25.80**	**26.32**	**yes**
GAM 135	**23.70**	**33.70**	**21.60**	**26.50**	**25.50**	**25.99**	**26.51**	**yes**
GAM 138	13.80	16.00	**21.60**	**24.60**	**23.08**	**23.54**	**23.99**	**yes**
GAM 159	**5.30**	**16.00**	No Data	No Data	**12.94**	**14.14**	**15.15**	**yes**
GAM 162	3.50	11.50	No Data	No Data	No Data	No Data	No Data	?
K/10/80	No Data	No Data	21.90	23.20	No Data	No Data	No Data	?
K/10/82	No Data	No Data	21.90	23.20	No Data	No Data	No Data	?
GAM 142	*23.70*	*33.70*	*30.00*	*30.00*	*31.30*	*31.88*	*32.43*	*yes*
K/10/75	No Data	No Data	24.40	26.80	No Data	No Data	No Data	?
K/10/77	No Data	No Data	24.40	26.80	No Data	No Data	No Data	?
K/10/79	No Data	No Data	24.40	26.80	No Data	No Data	No Data	?
GAM 188	*5.30*	*33.70*	*24.60*	*26.50*	*26.58*	*27.10*	*27.65*	*yes*
GAM 193	*23.70*	*33.70*	*24.60*	*26.50*	*30.53*	*31.19*	*31.84*	*yes*
GAM 197	No Data	No Data	No Data	No Data	30.86	31.63	32.39	?
GAM 435	**4.36**	**11.55**	**10.30**	**11.00**	**7.42**	**9.14**	**10.19**	**yes**
GAM 434	2.70	16.00	No Data	No Data	No Data	No Data	No Data	?
GAM 433	5.30	11.50	No Data	No Data	No Data	No Data	No Data	?
GAM 409	**3.50**	**11.50**	**5.05**	**5.37**	**2.57**	**4.72**	**5.35**	***yes***
GAM 413	3.50	11.50	2.90	5.30	17.33	17.65	17.97	no
GAM 423	*3.50*	*11.50*	*5.05*	*5.37*	*5.57*	*6.10*	*7.05*	*yes*
GAM 424	**3.50**	**11.50**	**5.37**	**7.70**	**4.42**	**5.24**	**5.70**	***yes***
GAM 426	*No Data*	*No Data*	*7.20*	*8.70*	*9.71*	*10.8*	*11.89*	*yes*
GAM 427	**4.00**	**5.95**	9.50	11.00	**5.19**	**5.74**	**6.31**	**yes**
GAM 103	**5.30**	**13.80**	**13.50**	**18.10**	**17.65**	**17.96**	**18.26**	**yes**
GAM 399	5.30	13.80	13.50	15.80	16.96	17.31	17.62	no
GAM 402	5.30	13.80	13.50	15.80	16.90	17.24	17.55	no
GAM 405	**15.10**	**20.40**	**18.10**	**19.70**	**18.89**	**19.18**	**19.51**	**yes**
GAM 297	No Data	No Data	No Data	No Data	15.61	16.20	16.64	?
GAM 320	No Data	No Data	No Data	No Data	9.78	10.77	11.74	?
GAM 332	5.30	11.50	11.00	11.50	15.14	15.79	16.27	no
GAM 334	5.30	16.00	11.00	12.45	16.48	16.84	17.19	no
GAM 335	**5.80**	**15.10**	**11.80**	**12.45**	**12.17**	**13.18**	**14.38**	***yes***
GAM 341	**5.30**	**16.00**	No Data	No Data	**15.91**	**16.48**	**16.95**	**yes**
GAM 342	5.30	16.00	No Data	No Data	18.15	18.44	18.71	no
GAM 347	*3.00*	*13.80*	*15.80*	*18.10*	*18.13*	*18.41*	*18.69*	*yes*
GAM 278	4.36	9.79	11.00	13.60	16.73	17.08	17.40	no
GAM 266	5.30	11.50	11.00	11.00	16.73	17.08	17.40	no
GAM 386	No Data	No Data	No Data	No Data	7.21	8.82	9.90	?
GAM 387	**10.53**	**23.20**	**9.50**	**11.00**	**11.00**	**12.09**	**13.39**	***yes***
GAM 391	*4.36*	*9.79*	*10.30*	*10.80*	*10.27*	*11.08*	*11.93*	*yes*
GAM 397	*0.00*	*16.00*	*10.90*	*11.80*	*6.35*	*7.22*	*8.87*	*yes*
GAM 429	**0.00**	**11.50**	**10.30**	**12.45**	**9.51**	**10.40**	**11.19**	**yes**
GAM 251					108.18	108.79	113.38	no

The assessment of consistency takes account of all the available information and is divided into the following categories (see also Table 2): Yes in **bold** – all three techniques are compatible (i.e. the age results are nested within each other). Yes in ***bold italic*** – two or more techniques are within error and have overlapping age ranges that are mutually compatible (but not nested within each other). Yes in *italic* – the ages are not within error of each other but lie in a similar geological time period (e.g. Oligocene versus Early Oligocene or Late Oligocene). No – the Sr data are inconsistent with well-constrained nannofossil or planktonic foraminiferal data or can be proven to be incorrect using other evidence (e.g. field relations or stratigraphic position). ? – insufficient data.
The criteria used for problematic samples are summarized below (see also text): GAM 177 nannos given priority; GAM 126 small sample; GAM 138 nannos given priority; GAM 159 forams accepted; no nannos; K/10/75, 77 & 79 nannos fit with stratigraphy; GAM 193 forams given priority; GAM 413 above top-Messinian unconformity; GAM 426 nannos accepted; GAM 399, GAM 402 & GAM 332 combined forams and nannos accepted, not Sr; GAM 342 forams used (no nannos); GAM 233 combined forams and nannos accepted, not Sr; GAM 391 planktonic forams well constrained and fit geology; GAM 397 age is consistent with geology.

the general Oligocene age derived from planktonic foraminifera. The three dating techniques do not produce a numerically consistent result for this sample (see Table 3). However, the general Oligocene age is in agreement with a previously reported Oligocene – Early Miocene age for the Arapköy (Klepini) Formation (Baroz, 1979). The planktonic foraminiferal dating of sample GAM 188 indicates a general Oligocene – Late Miocene age, while the nannofossils indicate a Chattian age (MNP25). As a result, the Sr age is generally consistent with both of the biostratigraphic ages (see Table 3). This is also consistent with a previously reported Late Oligocene age (Baroz, 1979).

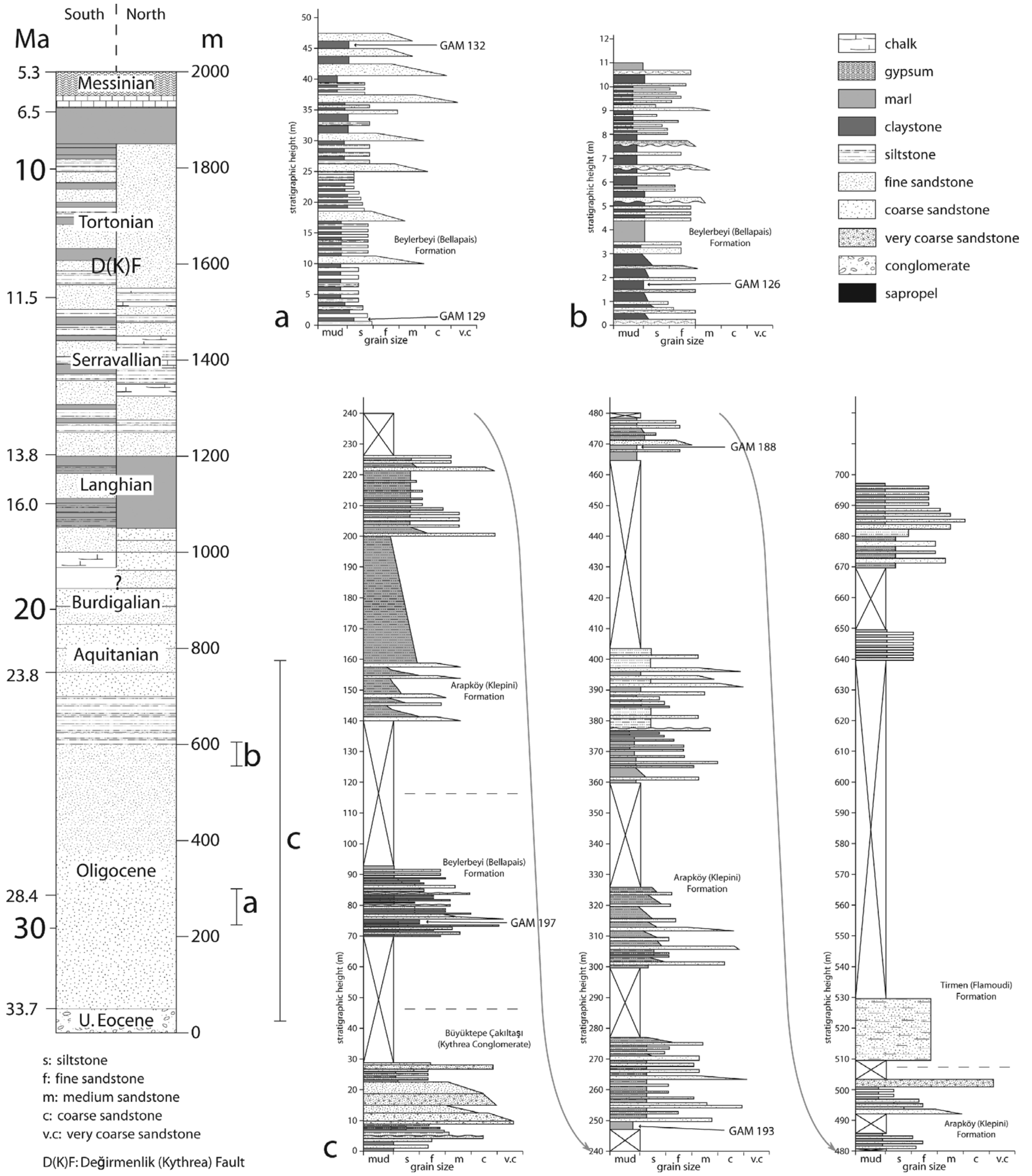

Figure 8. Composite sedimentary log of the Upper Eocene – Upper Miocene sedimentary rocks of the Değirmelik (Kythrea) Group (see left column). The successions exposed to the north and south of the Değirmenlik (Kythrea) Fault (D(K)F) are similar until the Middle Miocene when they diverged, mainly due to syn-sedimentary faulting (McCay & Robertson, 2012*a*). The approximate positions of logs a–c (to the right) measured in the Beylerbeyi (Bellapais) Formation (lower part of the succession) are marked on the summary column. The dated samples came from the following detailed sedimentary logs: (a, b) near Bahçeli (Kalograia); (c) road-cut at Yedikonuk (Eptakomi). Locations are shown in Figure 4.

A small number of additional samples were collected after the Sr dating had been completed in order to better date the Arapköy (Klepini) Formation using biostratigraphy alone. Three samples of fine-grained hemipelagic sediments (K/10/75, K/10/77 and K/10/79) were collected to the south of Mersinlik (Flamoudi) village. These yielded nannofossil ages ranging from 24.4 to 26.8 Ma (MNP25–MNN1) (Chattian), within the range of *Sphenolithus ciperoensis*. These ages are consistent with the nannofossil data from the other samples from this formation and so corroborate an Oligocene age for the Arapköy (Klepini) Formation.

2.d. Tirmen (Flamoudi) Formation: medium- to fine-grained calcareous sandstones and marls

Baroz (1979) originally defined this as the Flamoudi Formation, later translated as the Tirmen Formation by Hakyemez *et al*. (2000). The formation was originally named after Mersinlik (Flamoudi) village on the northern flank of the Girne (Kyrenia) Range, 19 km northeast of Geçitkale (Lefkoniko) village. The type locality was later relocated to Anamur Tepe, 750 m north of Tirmen (Trypiméni) village; i.e. 5 km northwest of Geçitkale (Lefkoniko), where the outcrop is relatively intact (Hakyemez *et al*. 2000).

The Tirmen (Flamoudi) Formation is extensively exposed on both the northern and southern flanks of the range. It comprises bioclastic calcareous sandstones and hemipelagic marls (Baroz, 1979), estimated as up to 200 m thick. Baroz (1979) originally subdivided the Tirmen (Flamoudi) Formation into three lithological units: calcareous sandstones, biogenic calcareous sandstones and mudstones. The calcareous sandstones form 10–20 cm thick beds that grade into fine-grained sandstones, calcareous siltstones and claystones. The calcareous sandstones exhibit excellent Bouma sequences, from T_a to T_d (Bouma, 1962). The presence of sedimentary structures including parallel and convolute lamination and sole structures confirms deposition by turbidity currents. The medium-grained sediments contain numerous beds that are rich in extra-basinal material as seen in the Beylerbeyi (Bellapais) Formation. Biogenic calcareous sandstones are mainly composed of planktonic and benthic foraminifera. Mudstones are pale coloured, with fine laminae that are mainly composed of planktonic foraminifera and nannoplankton.

The upper boundary of the formation is taken where marls and siltstone beds grade into reddish siltstones and marls of the overlying Geçitköy (Panagra) Formation (Baroz, 1979). This contact is occasionally marked by thin pebblestones, as seen in the eastern part of the range and around Değirmenlik (Kythrea) (Hakyemez *et al*. 2000).

2.d.1. *Dating evidence*

An Aquitanian–Burdigalian age was previously proposed from fossil evidence within biogenic-rich beds (Baroz, 1979; Hakyemez *et al*. 2000). Reworked Upper Oligocene fossils have also been reported (Baroz & Bizon, 1974; Baroz, 1979).

One sample (GAM 138 – GPS: 0556290, 3911516) was collected in the Bahçeli (Kalograia) area (Fig. 4) from grey marl interbedded with sandstone beds that are composed of calcareous lithic and shelly fragments. The planktonic foraminiferal assemblage in this sample includes *Catapsydrax dissimilis*, *Paragloborotalia mayeri*, '*Paragloborotalia*' *kugleri* and *Globigerina ciperoensis*, indicating a Langhian age, coupled with some reworking of taxa. The nannofossils are characteristic of biozones MNP25–MNN1 (Chattian–Aquitanian) (Table 2). The Sr age of 23.54 Ma (23.99–23.08 Ma; Chattian; Fig. 6) is older than expected. However, the combined error of the isotopic age (i.e. Chattian–Aquitanian) is within the nannofossil age range and is, therefore, consistent (see Table 3).

Two other samples were collected from the area surrounding Bahçeli (Kalograia) village (K/10/80 and K/10/82). These yielded nannofossil ages of 21.9–23.2 Ma (Aquitanian), within the range of the species *Sphenolithus disbelemnos*. This confirms that Aquitanian-aged sediments are present within the succession, although no Sr or planktonic foraminiferal data are available for this interval.

2.e. Geçitköy (Panagra) Formation: red hemipelagic marls

The Geçitköy (Panagra) Formation was first recognized by Moore (1960) as a marker horizon within his Kythrea Formation. Baroz (1979) described this formation as being composed of sandstones interbedded with bioclastic limestones and mudstones. The name Panagra Formation was assigned, later translated to the Geçitköy Formation by Hakyemez *et al*. (2000).

The Geçitköy (Panagra) Formation is named after Geçitköy (Panagra) village in the western part of the island, 17 km north of Güzelyurt (Morfou) town. The type locality is a road-cutting 800 m south of Geçitköy (Panagra) village, on the road to Çamlıbel (Myrtou). The formation is exposed on both the northern and southern flanks of the range. It is estimated to be up to 100 m thick along the northern flank of the range. However, thrusting along the southern front of the range precludes any accurate thickness measurement.

The base of the Geçitköy (Panagra) Formation is dominated by centimetre-scale, sharp-based beds of greenish grey to blue-green, fine-grained limestone. The limestone grades up into brick red-brown marl containing foraminifera-rich laminae, together with redeposited hemipelagic and biogenic detritus. There are also in frequent interbeds of light grey to dark red sandstones, 10–20 cm thick, with abundant epiclastic volcanic grains. Silicic tuffs rarely occur as a marker horizon. The upper boundary is characterized by beds of dull red to green sandstones and red marl. The upper boundary of the Geçitköy (Panagra) Formation is gradational and is represented by a change in colour and lithology to cream-grey calcareous sandstones and marls (Baroz, 1979), typical of the Esentepe (Trapeza) Formation.

2.e.1. *Dating evidence*

The Geçitköy (Panagra) Formation contains planktonic foraminifera that were previously taken to be indicative of the biozones *Praeorbulina* sp. and *Fohsella peripheroronda* of Langhian (Middle Miocene) age (Baroz & Bizon, 1974; Baroz, 1979). Planktonic foraminifera of the genera *Globoquadrina*, *Globorotalia*, *Praeorbulina* and *Orbulina* are also abundant.

Strontium analysis of a sample of the distinctive red marl (GAM 297 – GPS: 0542100, 3903734) in the Değirmenlik (Kythrea) area (Fig. 6) yielded an age of 16.20 Ma (16.64–15.61 Ma; Burdigalian). The

Burdigalian Sr age is within the combined error of the previously reported age of the Geçitköy (Panagra) Formation (Baroz, 1979).

In addition, several samples of lithologies similar to the Geçitköy (Panagra) Formation were collected from a road section near Ergenekon (Ayios Kharíton) (Fig. 9b). Two samples (GAM 341 – GPS: 0553355, 3908332; GAM 342 – GPS: 0553352, 3908351) from different local thrust slices yield ages of 16.48 Ma (16.95–15.91 Ma; Burdigalian–Langhian) and 18.44 Ma (18.71–18.15 Ma; Burdigalian), respectively (Fig. 6). Planktonic foraminifera (*Globigerinoides trilobus*, *Praeorbulina* sp., *Praegloborotalia siakensis*) from one sample (GAM 341) indicate a Middle–Late Miocene age. Planktonic foraminifera from sample GAM 342 include specimens of *Globorotalia mayeri* indicating a Middle–Late Miocene age (Fig. 7b). Biostratigraphic corroboration with nannofossils was not possible for either sample (GAM 341; GAM 342) because of poor preservation. The Sr age 16.48 Ma (16.95–15.91 Ma; Burdigalian–Langhian) for sample GAM 341 is within error of the biostratigraphic age. However, the Burdigalian Sr age of sample GAM 342 is not accepted because it is outside the error range of the well-constrained foraminiferal age (see Table 3).

2.f. Esentepe (Trapeza) Formation: grey/white marls

The Trapeza Formation was originally defined by Baroz (1979) and was later renamed the Esentepe Formation (Hakyemez *et al*. 2000). The type locality of the original Trapeza Formation (Baroz, 1979) is on the coastal plain north of Beşparmak (Trapeza) village, 11 km ESE of Girne (Kyrenia).

The lower part of the Esentepe (Trapeza) Formation is dominated by centimetre- to decimetre-scale beds that grade upwards from dark siltstone, rich in plant debris, through pale marl, to pale foraminifera- and nannofossil-rich marl and pelagic limestone. The upper part of the formation is mainly pale biogenic calcareous sandstone and siltstone (10–20 cm thick). Individual beds are occasionally well graded and locally contain diagenetic ironstone concretions.

The Esentepe (Trapeza) Formation, estimated to be up to 250 m thick, is mainly exposed on the northern flanks of the Girne (Kyrenia) Range in the west, with fewer outcrops on the southern flank. In the east, terrigenous material and calcareous sandstone are more abundant but with less abundant marl. The upper boundary of the formation is characterized by an increase in the thickness of calcareous sandstones, followed by an increase in terrigenous material marking the base of the Kaplıca (Davlos) Formation.

2.f.1. Dating evidence

Microfossils are more abundant than in the underlying Geçitköy (Panagra) Formation. The reported presence of the marker taxa *Paragloborotalia mayeri* and *Globorotalia menardii* were previously taken to indicate a Serravallian–Tortonian age (Baroz & Bizon, 1974; Baroz, 1979).

Beds of chalk with black organic-rich horizons, distinctive of the Esentepe (Trapeza) Formation, were sampled in several areas. One sample (GAM 426 – GPS: 0509520, 3908762) was collected from a pale to dark grey chalky marl with dark sapropel horizons and orange interbeds, near Hisarköy (Kambili) (Fig. 4). Sr analysis yields an age of 10.80 Ma (11.89–9.71 Ma) (Fig. 6), suggesting a Tortonian age, which is older than the nannofossil age (MNN11a) (Table 2). Although the numerical age ranges do not overlap (Table 3), both dating techniques indicate an age range within the Tortonian. Another sample (GAM 159 – GPS: 0555963, 3912577) was collected from a coastal road that runs past Bahçeli (Kalograia) village (Fig. 4); this yielded an age of 14.14 Ma (15.15–12.94 Ma; Langhian–Serravallian). Planktonic foraminifera from this sample indicate a Middle–Late Miocene age based on the presence of the guide fossil *Paragloborotalia mayeri*. The Sr result is within the combined error of the previously reported Serravallian–Tortonian age (Baroz, 1979). Rare nannofossils from this sample are not age diagnostic. A third sample (GAM 266 – GPS: 0560148, 3911238) was taken from a black organic-rich, sapropel horizon and yields a Late Miocene planktonic foraminiferal age (Table 2). Nannofossils from this sample are inferred to be from above the range of *Discoaster kugleri* but below the appearance of the genus *Catinaster* (∼11 Ma). The implied Sr age of 17.08 Ma (17.40–16.73 Ma; Burdigalian) is, therefore, likely to be too old (Fig. 6) and a Tortonian age is preferred.

Two samples (GAM 334 – GPS: 0553378, 3908294 and GAM 335 – GPS: 0553373, 3908309) were collected from thrust slices along the southern front of the range near Ergenekon (Ayios Kharíton) village (Figs 4, 9b). These yield ages of 16.84 Ma (17.19–16.48 Ma; Burdigalian) and 13.18 Ma (14.38–12.17 Ma; Langhian–Serravallian), respectively (Fig. 9b); i.e. within the Serravallian (GAM 335) and within the Burdigalian (GAM 334). Planktonic foraminifera in both samples yield a Middle–Late Miocene age: GAM 334 contains *Globoquadrina dehiscens*, while GAM 335 contains *Orbulina universa* (Table 2). The nannofossils yield Serravallian ages (i.e. GAM 334, MNN7; GAM 335, MNN7a) (Fig. 7b). The Sr age of sample GAM 335 is thus consistent with the planktonic foraminiferal age and is within error of the nannofossil age. However, sample GAM 334 is inconsistent because its combined error is outside the preferred biostratigraphic age of Serravallian (Fig. 6).

2.g. Kaplıca (Davlos) Formation: thick-bedded, massive fine-grained sandstones

The Davlos Formation as originally defined by Baroz (1979) was later subdivided by Hakyemez *et al*. (2000)

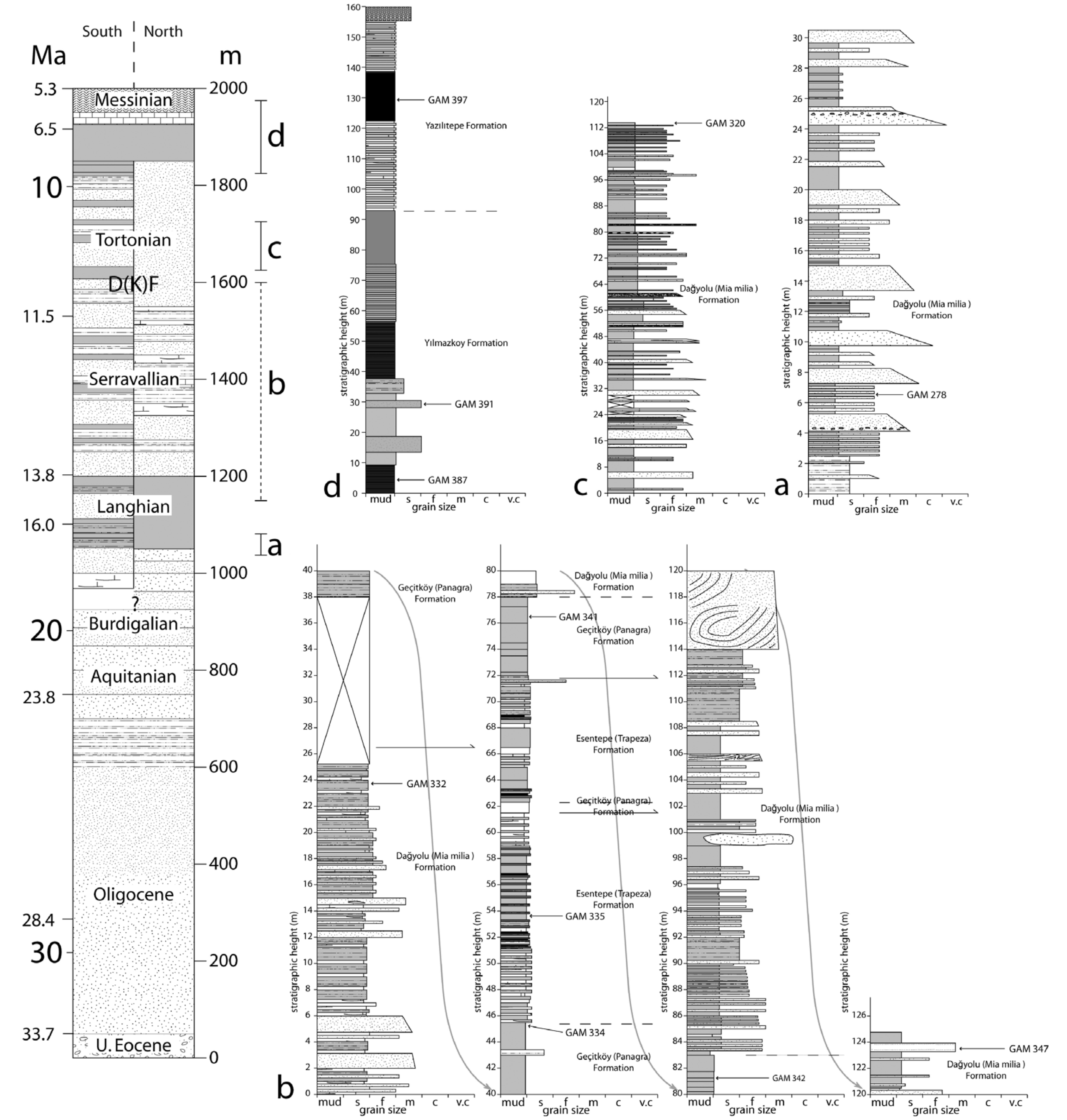

Figure 9. Composite sedimentary log of the Upper Eocene – Upper Miocene sedimentary rocks of the Değirmelik (Kythrea) Group as in Figure 8. Samples dated from the higher levels of the Upper Eocene – Upper Miocene Değirmelik (Kythrea) Group are shown on the following detailed sedimentary logs: (a) Geçitkale (Lefkoniko); (b) at Ergenekon (Ayios Kharíton); (c) Kalavaç (Kalyvakki); (d) stream section on 'gypsum hill' between Çınarlı (Platáni) and Altınova (Áyios Iákovos). For legend, please see Figure 8. Locations are shown in Figure 4.

into a lower sandstone-dominated formation, for which the name Davlos Formation was retained but translated into Turkish as the Kaplıca Formation. In addition, an overlying mudrock dominated unit was named the Yılmazköy Formation for the first time (Hakyemez *et al*. 2000). This subdivision was found to be valid during this work (G. McCay, unpub. Ph.D. thesis, Univ. Edinburgh, 2010).

The Kaplıca Formation is named after Kaplıca (Davlos) village on the northern side of the Girne (Kyrenia) Range, 12 km northeast of Geçitkale (Lefkoniko) village. The outcrop is located north of Kaplıca (Davlos) village, at Karaman Tepe on the northeast coast of the island. The formation as a whole is exposed north of the Değirmenlik (Kythrea) Fault, predominantly on the northern flank of the range. Outcrops are thickest in the east of the island (up to ∼200 m) and generally thin westwards.

The Kaplıca (Davlos) Formation consists of medium- to coarse-grained, brown to grey, lithic sandstones, siltstones and marlstones that generally grade westwards into marls of the Esentepe (Trapeza)

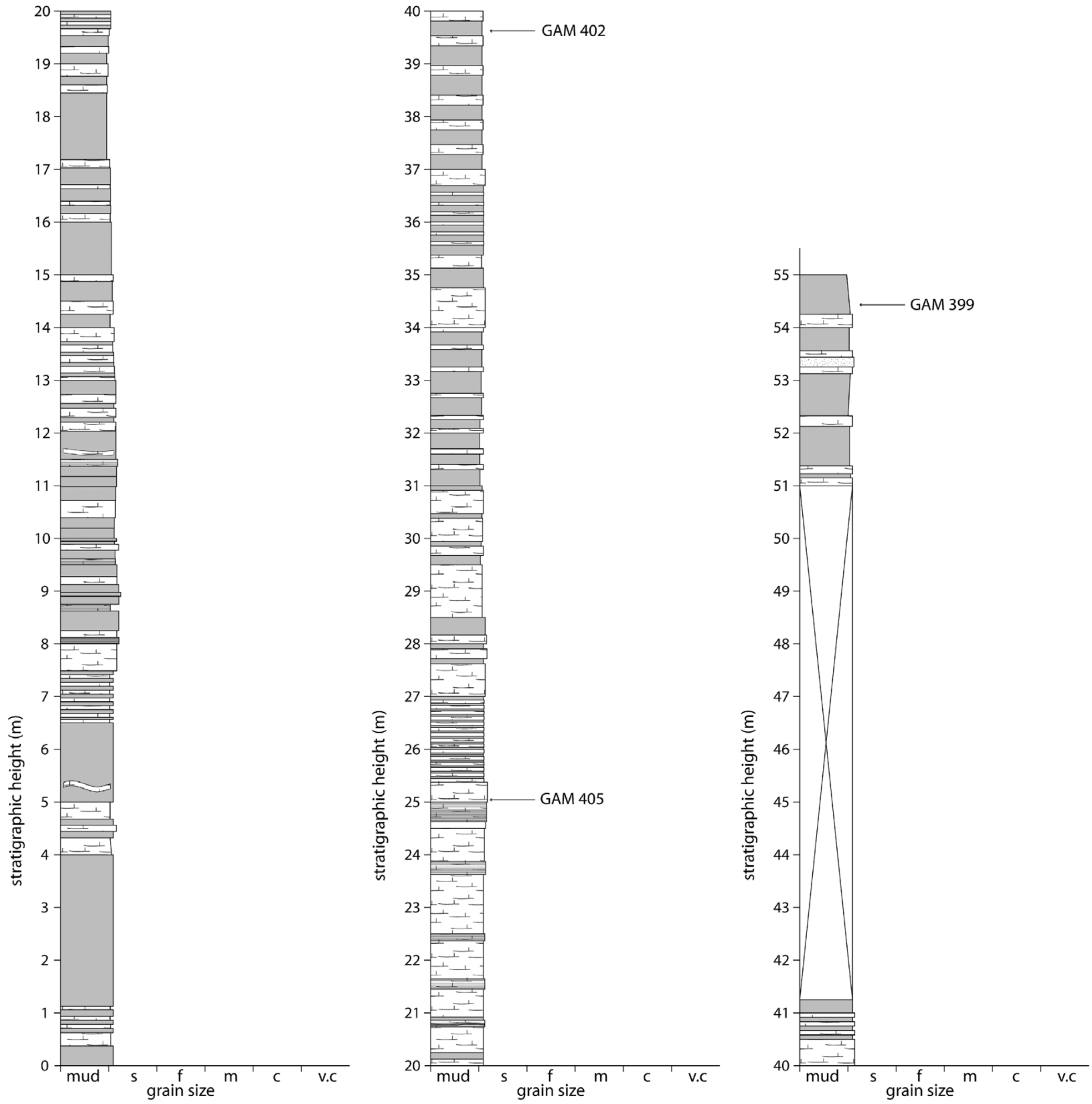

Figure 10. Sedimentary log of road-cut in the Dar Dere (Ovgos) area (see Fig. 1). This local outcrop differs from the other formations that are exposed to the north of the Değirmenik (Kythrea) Fault and is, therefore, not included within the composite log (Figs 8 & 9). For legend, please see Figure 8. Locations are shown in Figure 4.

Formation. In some exposures, the base of the formation is marked by a thin bed of pebblestone. White to pale-yellow silicic tuff and hyaloclastite occur as beds up to 3 m thick in some sections (e.g. directly south of Çınarlı (Platáni) village). The upper boundary of the Formation is conformable with the base of the overlying Yılmazköy Formation, which is characterized by an increase in mudstone and marl (Hakyemez *et al*. 2000).

2.g.1. Dating evidence

Sparse microfossils have in the past been used to assign the Kaplıca (Davlos) Formation to a Tortonian age, specifically the planktonic foraminifera *Neogloboquadrina acostaensis* (Baroz, 1979). No new Sr data were obtained owing to the scarcity of planktonic foraminifera in this terrigenous-dominated formation. One sample (GAM 433 – GPS: 0504233, 3911011), collected from close to Geçitköy (Panagra) village, yielded *Orbulina universa* and *Globoturborotalita nepenthes*, indicating an Late Miocene age. Another sample (GAM 162 – GPS: 0555991, 3912634) from Bahçeli (Kalograia) gave a Late Miocene–Early Pliocene age based on planktonic foraminifera including *Pulleniatina primalis* and *Globigerinella siphonifera*.

2.h. Dağyolu (Mia Milia) Formation: fine-grained sandstones and marls

This formation was originally defined as the Mia Milia Formation by Baroz (1979) and was renamed the Dağyolu Formation by Hakyemez *et al*. (2000). The formation is named after Mia Milia village (now Haspolat), 4 km north of Lefkoşa (Nicosia) in the Mesarya (Mesaoria) Basin. A new type locality was defined at Dağyolu (Fota) village, 20 km northwest of Lefkoşa (Nicosia) by Hakyemez *et al*. (2000). The Dağyolu (Mia Milia) Formation is only found in the Mesarya (Mesaoria) Basin to the south of the Değirmenlik (Kythrea) Fault. Its thickness was previously reported to range from 1 km (Hakyemez *et al*. 2000) to ∼1.6 km (Robertson & Woodcock, 1986), but is uncertain because of structural complications.

The Dağyolu (Mia Milia) Formation comprises yellowish-brown to grey sandstone turbidites. The sandstones are medium to fine grained with well-rounded to sub-rounded grains. Deposition from turbidity currents is indicated by well-developed sedimentary structures, including grading, flute and grove casts, and both parallel and convolute lamination. Interbedded siltstones are well laminated. Mudstone interbeds, up to ∼1 m in thickness, are commonly grey and structureless. Mudstone intercalations locally contain poorly preserved foraminifera and plant debris (Baroz, 1979). Rare white bioturbated calcareous claystone beds contain well-preserved foraminifera, calcareous nannoplankton and organic material.

The base of the Dağyolu (Mia Milia) Formation is directly underlain by red mudstones that are lithologically similar to the Geçitköy (Panagra) Formation, as exposed north of the Değirmenlik (Kythrea) Fault (Baroz, 1979). The Dağyola (Mia Milia) Formation passes conformably upwards into the Yılmazköy Formation (Hakyemez *et al*. 2000).

2.h.1. Dating evidence

Sparse planktonic foraminifera have previously been taken to indicate a Serravallian–Tortonian age (Baroz & Bizon, 1974; Baroz, 1979; Hakyemez *et al*. 2000).

One sample (GAM 320 – GPS: 0548817, 3904271) from a section near Kalavaç (Kalyvakki) (Figs 4, 9c) gives a Sr age of 10.77 Ma (11.74–9.78 Ma; Serravallian–Tortonian). This is consistent with the previously reported Serravallian–Tortonian age for the formation (Baroz, 1979; Hakyemez *et al*. 2000). Another sample (GAM 278 – GPS: 0565350, 3907635) that was collected from a new N–S road-cutting north of Geçitkale (Lefkoniko) (Figs 4, 9a) yields a Sr age of 17.08 Ma (17.40–16.73 Ma; Burdigalian) (Fig. 6). Planktonic foraminifera include *Globoturborotalita nepenthes*, indicating a Late Miocene–Late Pliocene (M13a–PL1) age (Table 2), whereas nannofossils give a Serravallian–Tortonian (MNN6–MNN7) age (Fig. 7b). The age ranges using the three methods do not overlap (see Table 3). However, the Middle–Late Miocene biostratigraphic ages are similar and so are accepted in preference to the Sr age.

A sample from near the Değirmenlik (Kythrea) Fault in the Ergenekon (Ayios Kharíton) section (GAM 347 – GPS: 0553334, 3908402) (Figs 4, 9b) gives a Sr age of 18.41 Ma (18.69–18.13 Ma; Burdigalian). Sample GAM 347 includes a foraminiferal assemblage of late Middle Miocene–Late Pliocene age, whereas nannofossil analysis gives a Burdigalian–Langhian age (MNN4a). The Sr age of sample GAM 347 is very similar to the age derived from the nannofossil assemblage, so that it is likely that deposition took place during Burdigalian–Langhian time, despite the age ranges (including error bars) not overlapping (see Table 3). The combined biostratigraphic and Sr results for sample GAM 347 are older than a previously reported Serravallian–Tortonian age (Baroz, 1979). A structurally lower sample (GAM 332 – GPS: 0553427, 3908247) yields a Sr age of 15.79 Ma (16.27–15.14 Ma; Burdigalian–Langhian) (Fig. 6), whereas a Late Miocene foraminiferal age is indicated by the presence of small specimens of *Orbulina universa* (Fig. 7b). Nannofossil analysis gives a Serravallian–Tortonian age (MNN7c) for this sample (GAM 332) (Fig. 7b). The Sr age of sample GAM 332 is discounted because it is inconsistent with both the planktonic foraminifera and nannofossil ages.

2.i. Yılmazköy Formation (former upper marl unit of the Davlos Formation): brown marls, mudstone and sandstone

The type locality of the Yılmazköy Formation is at Yılmazköy (Skylloura) village, 16 km northeast of Güzelyurt (Morfou). The formation is ∼200 m thick (Hakyemez *et al*. 2000) and is composed of light brown, yellowish, fine-grained sandstones and siltstones, interbedded with mudstones and marls. The mudstones are generally brownish, pale grey, or khaki coloured, commonly forming 1–2 cm thick partings, marked by bioturbation on the upper bed surfaces (Baroz, 1979). The Yılmazköy Formation is similar to the Esentepe (Trapeza) Formation such that in many areas it can only be distinguished by its higher stratigraphical position. The upper boundary of the Yılmazköy Formation is gradational with the overlying Yazılıtepe Formation (Hakyemez *et al*. 2000).

2.i.1. Dating evidence

Hakyemez *et al*. (2000) assigned a Tortonian age to the Yılmazköy Formation. During this work, a section of the Yılmazköy Formation was logged through an exposure of marl and gypsum on a hillside between Çınarlı (Platáni) and Altınova (Áyios Iákovos) villages (Figs 4, 9d). Two samples (GAM 387 – GPS: 0570757, 3910622; GAM 391 – GPS: 0570744, 3910683) give Sr ages of 12.09 Ma (13.39–11.00 Ma; Serravallian–Tortonian) and 11.08 Ma (11.93–10.27 Ma; Serravallian–Tortonian) (Fig. 6). Of these, sample GAM 387 yields a nannofossil age of Tortonian (MNN8–MNN9) and a planktonic foraminiferal age of Early–Late Miocene (23.2–10.53 Ma), while sample GAM 391 gives a more precise nannofossil age of Early Tortonian (MNN8b) (Table 2). This sample also contains *Orbulina universa* and *Globoturborotalita nepenthes*, indicative of a Late Miocene – Early Pliocene (M13a–PL1) age (Fig. 7b). However, samples GAM 387 and 391 gave generally consistent results and thus a Serravallian–Tortonian age is preferred.

Several samples of the Yılmazköy Formation were collected from near Geçitköy (Panagra) village (Fig. 4) where the succession is affected by thrusting and folding. This section was previously mapped as the Tirmen (Flamoudi) Formation of inferred Aquitanian–Burdigalian age (Baroz, 1979). One sample (GAM 435 – GPS: 0504439, 3911385) was collected from a bed of laminated cream-beige coloured marl, interbedded with limestone containing foraminifera. The planktonic foraminiferal assemblage, including *Orbulina universa* and *Globoturborotalita nepenthes*, indicates a Late Miocene – Early Pliocene (M11–PL1) age (Fig. 7b), while the nannofossils give a Serravallian–Tortonian age (MNN8a–MNN8b) (Fig. 7b). Sr analysis (Fig. 6) yields an age of 9.14 Ma (10.19–7.42 Ma; Tortonian). Although the nannofossil age range and the Sr age range do not overlap (see Table 3), their general consistency is suggestive of a Tortonian age.

2.j. Yazılıtepe Formation: chalk clay, limestone, sandstone and marls underlying the gypsiferous Lapatza Formation

The lower marl unit of the Lapatza Formation, named by Baroz (1979), was redefined as the Yazılıtepe Formation by Hakyemez *et al*. (2000). The Lapatza Formation was originally named after Lapatza Vouno, 2.4 km northwest of Yılmazköy (Skylloura) village. Hakyemez *et al*. (2000) redefined the type locality as being beneath gypsum at Mermertepe and Yazılıtep, south of Kılıçaslan (Kondeménos) village. Necdet & Anıl (2006) referred to Akdağ (white hill) near Türkeli (Áyios Vasílios) village and the area between Çınarlı (Platáni) and Altınova (Áyios Iákovos) villages as the best outcrops of this formation.

The Yazılıtepe Formation, estimated to be up to 100 m thick (Hakyemez *et al*. 2000), consists of marls, pelagic chalks and organic-rich mudstones. Thin- to medium-bedded, light grey to off-white coloured chalks and marls are observed in the lowest levels. Above this, the formation includes several facies of gypsum-bearing carbonate (Necdet & Anıl, 2006), locally associated with medium-bedded, laminated clay-rich limestones. Occasional thin beds of gypsiferous sandstone exhibit parallel and cross-lamination. The upper levels of the formation are characterized by organic-rich, black mudstones, rich in biogenic material, calcareous nannoplankton, planktonic foraminifera and fish fragments (Moore, 1960; Baroz, 1979; Necdet & Anıl, 2006).

The upper boundary of the Yazılıtepe Formation is conformable with the overlying Mermertepe (Lapatza) Formation, and is characterized by the incoming of weakly lithified gypsiferous sandstone (Hakyemez *et al*. 2000).

2.j.1. *Dating evidence*

The planktonic foraminifera *Neogloboquadrina acostaensis* and *Neogloboquadrina humerosa* were previously taken to indicate a Tortonian age (Baroz, 1979). Several recorded *Globigerina* species are consistent with this age (Necdet & Anıl, 2006). Rare fragments of the fish *Siphonostoma albyi* are also reported from within associated thin sapropels (Moore, 1960).

A sample (GAM 397 – GPS: 0570752, 3910757) from high in the section between the villages of Çınarlı (Platáni) and Altınova (Áyios Iákovos) (Figs 4, 9d) yields a Sr age of 7.22 Ma (8.87–6.35 Ma; Tortonian–Messinian; Fig. 6). This is consistent with the expected age just below the gypsum deposits. The nannofossil assemblage in this sample indicates an Early Tortonian to Messinian age (MNN7b–MNN8a; Table 2). The planktonic foraminiferal assemblage includes *Orbulina universa* (Middle Miocene – Recent) (Fig. 7b). Although the ages are not numerically consistent (see Table 3) they imply a Tortonian–Messinian age.

Two additional samples (GAM 386 – GPS: 0570123, 3911120; GAM 429 – GPS: 0572021, 3910420) were collected from localities between Çınarlı (Platáni) and Altınova (Áyios Iákovos) villages (Fig. 4). Sr analysis yields the following ages: GAM 386: 8.82 Ma (9.90–7.21 Ma; Tortonian–Messinian) and GAM 429: 10.40 Ma (11.19–9.51 Ma; Tortonian). As for sample GAM 435 (GPS: 504224, 3911149), GAM 429 includes *Orbulina universa* (Middle Miocene – Recent). The nannofossil assemblage (MNN7–MNN8b), the sparse planktonic foraminifera and the Sr ages are, therefore, consistent.

2.k. Mermertepe Gypsum (formerly gypsiferous unit of the Lapatza Formation)

Grey marl and gypsum beds were reported by Bellamy & Jukes-Browne (1905) and later named the Lapatza Gypsum Lens by Henson, Browne & McGinty (1949). This was redefined as part of the Lapatza Formation by Weiler (1969) and this name that was retained by Baroz (1979) for the evaporite-related facies as a whole. The formation was originally named after Lapatza Vouno, 2.4 km northwest of Yılmazköy (Skylloura) Village (Henson, Browne & McGinty, 1949). Recently, Hakyemez *et al*. (2000) applied the name Mermertepe Gypsum.

The Mermertepe Gypsum crops out at about 22 reported localities scattered across the Mesarya (Mesaoria) Basin and the Karpaz (Karpas) Peninsula (Necdet & Anıl, 2006). The formation is commonly seen in outcrops exposing 10–30 m of succession. Coarse selenite-type gypsum is commonly interbedded with fine-grained, laminated, alabastrine-type gypsum. Enterolithic (chicken-wire) texture is occasionally seen within laminated, crystalline gypsum and rarely within anhydrite. Other less common evaporitic facies include nodular and recrystallized gypsum, gypsiferous limestones and microbial (stromatolitic) gypsum (Necdet & Anıl, 2006). Reworking to form detrital gypsum facies is present locally (e.g. at Mehmetçik (Galatia) village; Necdet & Anıl, 2006).

The upper boundary of the Mermertepe Gypsum is an angular unconformity with the overlying Pliocene Çamlıbel (Myrtou) Formation, following an important phase of deformation (Robertson & Woodcock, 1986; McCay & Robertson, 2012*b*).

Few fossils are present in the gypsiferous limestone facies because of unfavourable, hypersaline conditions during the Messinian (e.g. Hsü, Cita & Ryan, 1973).

2.l. Unnamed formation: white and pink pelagic carbonates south of the Değirmenlik (Kythrea) Fault

Contrasting facies are exposed to the south of the Değirmenlik (Kythrea) Fault (Fig. 1). To the south of the Girne (Kyrenia) Range pelagic carbonates are exposed along a road-cutting, near Dar Dere (Ovgos) (Fig. 4). The chalks were previously assigned to the Lapithos (Lapta) Formation by Baroz & Bizon (1974) and also by Harrison *et al*. (2004). These facies are quite similar to the Pakhna Formation (Late Oligocene – Late Miocene) of the circum-Troodos succession (Eaton & Robertson, 1993; Lord *et al*. 2000). In detail, however, the facies exposed near Dar Dere (Ovgos) appear to be significantly different from elsewhere, although no formal stratigraphy has yet been established. A general feature of these sediments is the evidence of widespread gravity redeposition that can be explained by syn-depositional movements along the nearby Değirmenlik (Kythrea) Fault zone.

2.l.1. Dating evidence

Sr ages were obtained from three samples of pelagic chalk from an ascending sequence along a road-cutting near Dar Dere (Ovgos) (Figs 4, 10). The sample from the highest stratigraphic position (sample GAM 399 – GPS: 0509717, 3898182) gives an age of 17.31 Ma (17.62–16.96 Ma; Burdigalian) (Fig. 6), older than the nearby sample GAM 402 stratigraphically beneath (17.24 Ma (17.55–16.90 Ma; Burdigalian). However, the combined errors of the two samples overlap. Nannofossil assemblages from samples GAM 399 and GAM 402 are indicative of a Middle Miocene age (MNN5–MNN5a; or Langhian) (Fig. 7b). Both samples contain planktonic foraminifera of Middle–Late Miocene age. Samples GAM 399 and GAM 402 are, therefore, likely to be of late Middle Miocene age.

The sample in the stratigraphically lowest position in the sequence discussed above (GAM 405 – GPS: 0509864, 3898131) yields a Sr age of 19.18 Ma (18.89–19.51 Ma; Burdigalian). In agreement, the nannofossil assemblage indicates an Early Miocene age (MNN3a; Burdigalian). Planktonic foraminifera indicate a late Early Miocene – early Middle Miocene age. However, the inclusion of *Paragloborotalia mayeri* and also of very rare specimens of *Praeorbulina glomerosa*, *Praeorbulina sicana* and ‘*Paragloborotalia*’ *kugleri* (see Fig. 7b) indicates that significant reworking has taken place. In addition, nannofossils from a nearby locality have yielded an age of NN4 (Early Miocene) (Harrison *et al*. 2004).

A fourth sample (GAM 103 – GPS: 0511141, 3895893), comprising pink marl, was collected to the west of Dar Dere (Ovgos) and yielded an age of 17.96 Ma (18.26–17.65 Ma; Burdigalian). In contrast, planktonic foraminifera from this sample include *Globigerinoides sacculifer*, *G. bisphericus*, *Orbulina universa*, *O. suturalis*, *Praeorbulina glomerosa* and *Globoquaderina dehiscens*. This assemblage is indicative of a Middle – Late Miocene age (13.8–5.3 Ma). The nannofossil assemblage indicates a Langhian–Serravallian age (15.6–13.5 Ma) (i.e. in the uppermost range of *Helicosphaera ampliaperta*). The nannofossil and Sr ages are thus in agreement while the nannofossil age is consistent with the age range derived from planktonic foraminifera (see Table 3). A Middle Miocene age is likely, although the isotopic and planktonic foraminiferal ages are not consistent.

3. Pliocene sediments

Upper Miocene sedimentation was terminated by an important phase of southward-directed thrusting and folding that affected the Girne (Kyrenia) Range and its foreland at least as far south as, and including, the Dar Dere (Ovgos) Fault (Ducloz, 1972; Baroz, 1979; Robertson & Woodcock, 1986; Harrison *et al*. 2004; McCay & Robertson, 2012*a, b*). As a result the Pliocene sediments overlie a regional unconformity. The formal stratigraphy of the Pliocene sediments is outside the scope of this paper (see Baroz, 1979 and Hakyemez *et al*. 2000). However, several samples were collected for dating from near the base of the Pliocene succession in order to define the age of the unconformity. Where exposure is poor, dating was in any case needed to distinguish Upper Miocene and Pliocene sediments.

Several samples were studied from a section near Hisarköy (Kambili) in the western range (Fig. 5). A sample of brown marl (GAM 409 – GPS: 0508152, 3909379) was collected stratigraphically above an unusual conglomerate that is dominated by clasts of alabastrine and selenitic gypsum. The Sr age of GAM 409 is 4.72 Ma (5.35–2.57 Ma; Messinian–Gelasian), which places it within the Zanclean (Early Pliocene) (Fig. 6). Another sample (GAM 413 – GPS: 0508318, 3909673) was collected stratigraphically below the gypsum conglomerate. The planktonic foraminiferal assemblage (e.g. *Sphaeroidinellopsis seminulina*, *Neogloboquadrina humerosa* and *Globigerinoides obliquus*) indicates a Late Miocene – Early Pliocene age, similar to sample GAM 409 (Fig. 7b; Table 2). In agreement, nannofossil determinations yield a Pliocene age (MNN12). In contrast, the Sr analysis for GAM 413 gives an age of 17.65 Ma (17.97–17.33 Ma; Burdigalian). A Zanclean age (derived from sample GAM 409) is in agreement with the field evidence that

Table 4. Summary of the reliable Sr age data for each of the recognized formations

Formation	Oldest Sr result	Youngest Sr result	Oldest Sr error	Youngest Sr error
Çamlibel (Myrtou)	6.10	4.72	7.05	2.57
Mermertepe (Lapatza)	Samples from the Mermertepe (Lapatza) not suitable for fossil preservation			
Yazılıtepe	10.40	7.22	11.19	6.35
Yılmazköy	12.09	9.14	13.39	7.42
Dağyolu (Mia Milia)	18.41	10.77	18.69	9.78
Esentepe (Trapeza)	14.14	10.80	15.15	9.71
Geçitköy (Panagra)	16.48	16.20	16.95	15.61
Tirmen (Flamoudi)	23.54	–	23.99	23.08
Arapköy (Klepini)	31.19	25.99	31.84	25.50
Beylerbeyi (Bellapais)	31.88	25.80	32.43	25.33
Dar Dere (Ovgos) unnamed formation	19.18	17.96	19.23	17.65

The maximum and minimum accepted ages (in Ma) are shown, followed by the maximum and minimum combined error for the ages for each formation. Only Sr data that are consistent with the well-constrained biostratigraphic results are included. The assessment of the age data is summarized in Tables 2 & 3 and discussed in the text (see also the online Supplementary Material available at http://journals.cambridge.org/geo).

the marl and conglomerate were formed after the deposition and erosion of the Messinian gypsum; thus the Sr age is inconsistent. Previously these marls and clays were mapped as undistinguished Upper Miocene – Pliocene sediments (Baroz, 1979). The inconsistent Sr age is likely to be due to sediment reworking above the regional unconformity.

In addition, one sample (GAM 424 – GPS: 0508951, 3909106) was collected in the Hisarköy (Kambili) area (Fig. 4) to determine the age of the typical marl deposits above a thin basal conglomerate with gypsum clasts. The presence of cross-cutting thrusts coupled with homogenous brown marl deposits makes age determination difficult from field evidence alone. In places, the conglomerate is exposed below the Messinian gypsum as a result of thrusting. Sr dating indicates an age of 5.24 Ma (5.70–4.42 Ma; Messinian–Zanclean) (Fig. 6). Nannofossil dating yields a Messinian (MNN11b–MNN11c) age, while the planktonic foraminifera include *Orbulina universa* (Late Miocene – Early Pliocene) (Fig. 7).

Other samples (GAM 423 – GPS: 0508720, 3909223, GAM 427 – GPS: 507788, 3909600) were collected from outcrops of gypsiferous sandstone near Hisarköy (Kambili). These yield dates within the Messinian–Zanclean; i.e. 6.10 Ma (7.05–5.57 Ma) for GAM 423 and 5.74 Ma (6.31–5.19 Ma) for GAM 427. Sr ages close to, or within, the Messinian Stage are likely to be unreliable owing to the isolation of the Mediterranean from the global ocean during this time (Flecker, de Villiers & Ellam, 2002). Nannofossil dating of sample GAM 427 indicates a Messinian age (MNN8–MNN9), whereas sample GAM 423 yielded an Early Pliocene age (MNN12). Planktonic foraminifera in GAM 423 include *Neogloboquadrina acostaensis* (Late Miocene – Early Pliocene). A Messinian to Pliocene age (M14–PL2) for sample GAM 427 is inferred based on the occurrence of *Orbulina universa* and *Globorotalia margaritae*. The detrital gypsiferous sediments are, therefore, interpreted as having accumulated during the Early Pliocene in response to the reworking of Messinian gypsum.

4. Discussion

The Sr isotopic dates (with ranges) that are considered to be an accurate indication of the timing of deposition, as constrained by the available calcareous nannoplankton and planktonic foraminiferal data (see Tables 2 and 3), are summarized in Table 4. The resulting biochronology of the Eocene–Pliocene sediments studied is shown in Figure 11. It is apparent that there is a considerable overlap in the ages assigned to several of the formations. There are several possible reasons for this. First, the combined errors of the accepted Sr ages allow for a considerable overlap in the ages of the formations, particularly where samples are taken close to the formation boundaries, as assigned by field mapping and lithostratigraphy. Secondly, some lithological boundaries are gradational in different sections and thus to some extent arbitrary. For example, a sample of a given age placed near the base of one formation might be placed near the top of the underlying formation for another sample of the same age in a different section. Thirdly, there could be regional-scale facies variation within a thick succession of largely gravity-deposited sediments. For example, thick-bedded, channelized turbidites in one section might correspond to thin-bedded overbank turbidite deposits or hemipelagic deposits in a different section and thus be placed in a different formation (McCay & Robertson, 2012*a*). However, all of the formations can be recognized throughout the Girne (Kyrenia) Range as a whole and assigned to one overall stratigraphy. The main causes of overlapping formation ages are, therefore, likely to be imprecision in absolute assigned age coupled with local facies variation.

Despite the above limitation, the results indicate some significant age differences compared to pre-existing stratigraphical schemes. (1) Facies correlated with the Beylerbeyi (Bellapais) Formation extend into the Oligocene (Rupelian), suggesting that the overlying Arapköy Formation is largely restricted to the Late Oligocene (Chattian). (2) Although previously assigned to the Langhian, the Geçitköy (Panagra) Formation appears to be older, i.e. Burdigalian–Langhian. (3) The

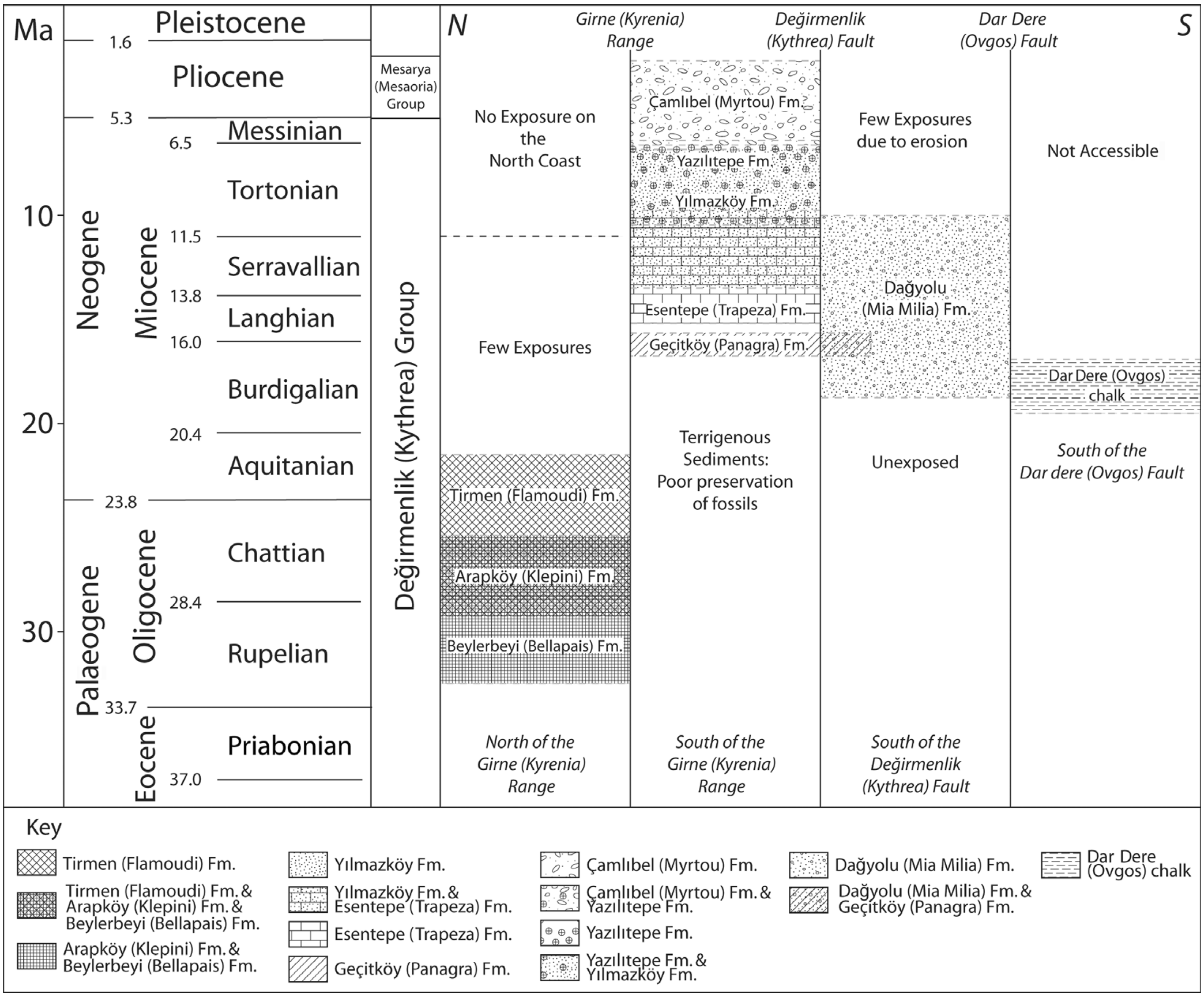

Figure 11. Stratigraphy and biochronology of the Upper Eocene – Upper Miocene sediments of the Girne (Kyrenia) Range resulting from this study. The age ranges of the various formations are summarized mainly utilizing Sr age data that are corroborated with well-constrained calcareous nannoplankton and planktonic foraminiferal dating. Possible reasons for the implied overlap in some formation ages are discussed in the text.

Esentepe (Trapeza) Formation is also older, with its lower beds having a Langhian age. (4) The overlying very thick-bedded sandstone turbidites of the Kaplıca (Davlos) Formation are mainly Tortonian. They too are likely to be older than previously believed, possibly beginning to accumulate during the Serravallian. (5) To the south of the Değirmenlik (Kythrea) Fault the Dağyolu (Mia Mila) Formation extends back at least to the Burdigalian and thus is more long ranging than previously appreciated (i.e. Serravallian–Tortonian). (6) Pelagic marls exposed within the Dar Dere (Ovgos) fault lineament, dated as Burdigalian, are lithologically dissimilar to the mudrocks and sandstone turbidites of the Upper Oligocene – Lower Miocene Tirmen (Flamoudi) Formation, as exposed on both flanks of the Girne (Kyrenia) Range to the north of the Değirmenlik (Kythrea) Fault. However, the stratigraphy of these Lower Miocene pelagic sedimentary rocks remains uncertain largely owing to faulting. (8) Our biostratigraphical ages are consistent with the previously reported Tortonian–Messinian ages for the pre-evaporitic Yilmazköy Formation and the Yazıltepe Formation. However, accurate isotopic dating of Upper Miocene sediments in the Mediterranean is precluded by the Messinian salinity crisis. The new results of Sr isotopic dating, combined with the new nannofossils and planktonic foraminiferal dating, therefore, provide a realistic stratigraphy and biochronology for the Upper Eocene to Lower Pliocene sedimentary rocks exposed in the north of Cyprus.

The majority of the samples yielded Sr isotopic ages that are in agreement with the nannofossil and/or the planktonic foraminiferal ages. However, some Sr dates are inconsistent with the biostratigraphy (i.e. outside the combined error) and had to be discounted as discussed above (Tables 2 and 3). There are several possible explanations of the inconsistencies in the age results from the three different methods. (1) In one case the sample was probably too small to permit reliable age determination. (2) Some samples of planktonic foraminifera, although not visibly recrystallized (and thus suitable for strontium dating) were abraded, suggestive of reworking. (3) The inferred sedimentary environment involving widespread gravity deposition in the form of mass flows and turbidites (McCay & Robertson, 2012*a*) is consistent with widespread reworking and sediment redeposition. Even the fine-grained tops of turbidites and interbedded hemipelagic sediments that were preferentially sampled are liable to sediment reworking. (4) The Upper Eocene – Oligocene and also the Lower Pliocene sediments accumulated above important regional unconformities show petrographic evidence of reworking of older material (McCay & Robertson, 2012*a*). (5) In several cases apparently older samples come above definitely younger samples in the logged stratigraphy, which could reflect sediment reworking. (6) In several cases planktonic foraminifera of different (incompatible) age ranges co-occur in a single sample, effectively proving that reworking of older into younger assemblages must have taken place. (7) The analysed planktonic foraminifera could contain significant numbers of older taxa that were not identified because of their abraded or fragmentary state, again owing to reworking. (8) Even where planktonic foraminifera were identified some taxa are typically long-ranging forms that could have been reworked.

Further evidence of sediment reworking comes from the comparison of the age data from the three different methods. In a number of cases, samples that are inferred to have accumulated during Late Miocene or late Middle Miocene time, based mainly on the nannofossil and/or planktonic foraminifera data, yielded Burdigalian Sr isotopic ages. The Sr ages that are classed as inconsistent commonly fall into a relatively narrow age range of 16.48–18.44 Ma (e.g. samples GAM 266, GAM 278 and GAM 413). These samples were deposited during a period of increased sedimentation rate. For example, samples GAM 266, GAM 278 and GAM 347 were all expected to be of Serravallian–Tortonian age, which was corroborated by biostratigraphic data indicating a Late Miocene age. This time interval was followed by the deposition of thick, massive sandstone beds (up to 3 m thick, individually), belonging to the Kaplıca (Davlos) Formation. Palaeocurrent data show that the turbidites were mainly derived from the east and northeast of Cyprus (McCay & Robertson, 2012*a, b*). In this region, the Southern Neotethyan Ocean finally closed resulting in the collision of the Anatolian (Eurasian) and Arabian (African) plates during Early Miocene time (Robertson *et al*. 2004, 2007). This was coupled with strong uplift of the over-riding plate based on evidence of fission-track dating (Okay, Zattin & Cavazza, 2010). In contrast, as a result of diachronous continental collision the Girne (Kyrenia) Range remained in a relict oceanic basin to the west and continued to undergo deep-sea deposition until the Messinian salinity crisis. It is, therefore, probable that during the collision to the east the upper part of the pre-existing deep-sea sedimentary sequence, of mainly Early Miocene (Burdigalian) age, was uplifted and reworked westwards as gravity flows during late Middle Miocene – Late Miocene time. This important regional sediment redeposition event could only be inferred from comparative age datasets as used here.

5. Conclusions

(1) An integrated lithostratigraphy is proposed for sediments of Late Eocene – Pliocene age within the Girne (Kyrenia) Range based on fieldwork throughout this nearly 200 km long lineament. The previous, longstanding stratigraphy is significantly changed for the Middle–Late Miocene (Serravallian–Tortonian) during which time two formations accumulated to the north of an E–W syn-sedimentary fault lineament, while a single long-ranging formation formed to the south of this tectonic feature. The Late Miocene culminated in three formations including Messinian gypsum that overlaps the fault lineament.

(2) Previously undated turbiditic sediments from one area in the east of the range were found to be of Late Cretaceous age based on planktonic foraminiferal and calcareous nannofossil evidence. These sediments provide a window into sediment accumulation in a pre-existing deep-sea basin located along the southern margin of the Tauride microcontinent.

(3) The Pliocene sediments accumulated following an important phase of thrusting and folding.

Biostratigraphical data support field evidence of extensive reworking of Messinian gypsum at the base of the unconformably overlying Lower Pliocene (Zanclean) succession.

(4) Sr dating provides a realistic biochronology of the Upper Eocene–Pliocene formations, but only when tested against well-constrained dating using calcareous nannoplankton and planktonic foraminifera. A significant number of the Sr age results cannot be considered as true sediment depositional ages because they are incompatible with (i.e. outside the relevant ages of) the planktonic foraminifera or the nannofossils, or both. The main reason for the discrepant ages is reworking of the foraminifera used for Sr dating. This is consistent with sedimentological evidence of sediment redeposition and textural evidence of abrasion and fragmentation of many planktonic foraminifera in samples used for Sr dating.

(5) Strong evidence of sediment reworking is given by preferential Early Miocene Sr ages that are incompatible with well-constrained late Middle–Late Miocene biostratigraphical ages. In the light of palaeocurrent data, this is explained as a response to tectonic uplift and sediment redeposition in an area to the east of the Girne (Kyrenia) Range. This basinal area was uplifted and reworked during collision of the Anatolian (Eurasian) and Arabian (African) plates during Early Miocene time. In contrast, deep-sea sedimentation continued further west in the vicinity of the Girne (Kyrenia) Range until the Messinian salinity crisis.

(6) Strontium dating is commonly used to date sedimentary successions on its own, or to fill gaps in an available biostratigraphy. However, as shown by this

study, significant errors can result, especially related to sediment working. Sr dating is instead most effective when combined with biostratigraphical dating of the same samples, preferably using as many methods as possible.

(7) The approach advocated here involves the comparison of large datasets using different methods for individual samples, and this can also reveal important geological events (e.g. large-scale sediment reworking) that would not otherwise be recognizable.

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References

ARMSTRONG, H. A. & BRASIER, M. D. 2005. *Microfossils*, 2nd ed. Oxford: Blackwell Publishing, 296 pp.

BAROZ, F. 1979. Etude géologique dans le Pentadaktylos et la Mesaoria (Chypre Septentrionale). Thèse pour l'obtention du grade de Docteur d'État mention Sciences. Université de Nancy, Nancy, France. Published thesis.

BAROZ, F. & BIZON, G. 1974. Le Néogène de la chaîne du Pentadaktylos et de la partie nord de la Mésaoria (Chypre); étude stratigraphique micropaléontologique. *Revue de l'Institut Français du Pétrole* **29** (3), 327–59.

BELLAMY, C. V. & JUKES-BROWNE, A. J. 1905. *The Geology of Cyprus*. Plymouth: William Brendon and Son Ltd, 72 pp.

BERGGREN, W. A., KENT, D. V., SWISHER, C. C., III & AUBRY, M.-P. 1995. A revised Cenozoic geochronology and chronostratigraphy. In *Geochronology, Time Scales and Global Stratigraphic Correlation* (eds W. A. Berggren, D. V. Kent, M.-P. Aubry & J. Hardenbole), pp. 129–212. Tulsa, Oklahoma: Society of Economic Paleontologists and Mineralogists, Special Publication 54.

BOULTON, S. J., ROBERTSON, A. H. F., ELLAM, R. M., SAFAK, Ü. & ÜNLÜGENÇ, U. C. 2007. Strontium isotopic and micropalaeontological dating used to redefine the stratigraphy of the Neotectonic Hatay Graben, southern Turkey. *Turkish Journal of Earth Sciences* **16**, 141–79.

BOUMA, A. H. 1962. *Sedimentology of Some Flysch Deposits: a Graphic Approach to Facies Interpretation*. Amsterdam: Elsevier.

CANDE, S. C. & KENT, D. V. 1995. Revised calibration of the geomagnetic polarity timescale for the Late Cretaceous and Cenozoic. *Journal of Geophysical Research* **100**, 6093–5.

DUCLOZ, C. 1972. *The Geology of the Bellapais-Kythrea Area of the Central Kyrenia Range*. Geological Survey Department of Cyprus Bulletin 6.

EATON, S. & ROBERTSON, A. H. F. 1993. The Miocene Pakhna Formation, southern Cyprus and its relationship to the Neogene tectonic evolution of the eastern Mediterranean. *Sedimentary Geology* **86**, 273–96.

FLECKER, R. & ELLAM, R. M. 1999. Distinguishing climatic and tectonic signals in the sedimentary successions of marginal basins using Sr isotopes: an example from the Messinian salinity crisis, Eastern Mediterranean. *Journal of the Geological Society, London* **156**, 847–54.

FLECKER, R., ELLAM, R. M., MÜLLER, C., POISSON, A., ROBERTSON, A. H. F. & TURNER, J. 1998. Application of Sr isotope stratigraphy and sedimentary analysis to the origin and evolution of the Neogene basins in the Isparta Angle, southern Turkey. *Tectonophysics* **298**, 83–101.

FLECKER, R., DE VILLIERS, S. & ELLAM, R. M. 2002. Modelling the effect of evaporation on the salinity-$^{87}Sr/^{86}Sr$ relationship in modern and ancient marginal-marine systems; the Mediterranean salinity crisis. *Earth and Planetary Science Letters* **203**, 221–33.

HAKYEMEZ, Y., TURHAN, N., SÖNMEZ, İ. & SÜMENGEN, M. 2000. *Kuzey Kıbrıs Türk Cumhuriyeti' nin Jeolojisi*. MTA (Geology of the Turkish Republic of Northern Cyprus). Genel Müdürlüğü Jeoloji Etütleri Diaresi, Ankara (MTA), 44 pp.

HAKYEMEZ, A. & ÖZKAN-ALTINER, S. 2007. Beşparmak Dağları'ndaki (Kuzey Kıbrıs) Üst Maastrihtiyen-Eosen istifinin planktonik foraminifer biyostratigrafisi (Planktic foraminiferal biostratigraphy of the Upper Maastrichtian–Eocene sequence in the Beşparmak Range, Northern Cyprus). *60th Geological Congress of Turkey*, *Ankara, Abstract*, pp. 416–19.

HARRISON, R. W., NEWELL, W. L., BATIHANLI, H., PANAYIDES, I., MCGEEHIN, J. P., MAHAN, S. A., OZHUR, A., TSIOLAKIS, E. & NECDET, M. 2004. Tectonic framework and Late Cenozoic tectonic history of the northern part of Cyprus: implications for earthquake hazards and regional tectonics. *Journal of Asian Earth Sciences* **23**, 191–210.

HENSON, F. R. S., BROWNE, R. V. & MCGINTY, J. 1949. A synopsis of the stratigraphy and geological history of Cyprus. *Quarterly Journal of the Geological Society of London* **CV**, 2–37.

HOWARTH, R. J. & MCARTHER, J. M. 1997. Statistics for strontium isotope stratigraphy: a robust LOWESS fit to the marine strontium isotope curve for the period 0 to 206 Ma, with look-up table for the derivation of numerical age. *Journal of Geology* **105**, 441–56.

HSÜ, K. J., CITA, M. B. & RYAN, W. B. F. 1973. The origin of the Mediterranean evaporites. In *Initial Reports of the Deep Sea Drilling Project*, Vol. XIII (eds W. B. F. Ryan, K. J. Hsü & M. B. Cita), pp. 1203–31. Washington, DC: US Government Printing Office.

LORD, A. R., PANAYIDES, A., URQUHART, E. & XENOPHONTOS, C. 2000. A biostratigraphical framework for the Late Cretaceous-Recent circum-Troodos sedimentary sequence, Cyprus. In *Proceedings of the Third Internal Conference on the Geology of the Eastern Mediterranean* (eds I. Panayides, C. Xenophontos, & J. Malpas), pp. 289–98. Nicosia: Geological Survey Department of Cyprus.

MARTINI, E. 1971. Standard Tertiary and Quarternary calcareous nannoplankton zonation. In *Proceedings of the II Planktonic Conference, Rome* (ed. A. Farinacci), pp. 739–85.

MCCAY, G. & ROBERTSON, A. H. F. 2012*a*. Late Eocene–Neogene sedimentary geology of the Girne (Kyrenia) Range, northern Cyprus: a case history of sedimentation related to progressive and diachronous continental collision. *Sedimentary Geology* **265–266**, 30–55.

McCay, G. & Robertson, A. H. F. 2012*b*. Upper Miocene–Pleistocene deformation of the Girne (Kyrenia) Range and Dar Dere (Ovgos) lineaments, N Cyprus: role in collision and tectonic escape in the easternmost Mediterranean region. In *Geological Development of the Anatolia and the Easternmost Mediterranean Region* (eds A. H. F. Robertson, O. Parlak & U. C. Ünlügenç). Geological Society of London, Special Publication no. 372, first published online 5 September 2012. doi: 10.1144/SP372.6

Miller, K. G., Feigenson, M. D., Kent, D. V. & Olsson, R. K. 1988. Oligocene stable isotope (^{87}Sr/^{86}Sr, delta ^{18}O, delta ^{13}C) standard section, Deep Sea Drilling Project Site 522. *Palaeoceanography* **3**, 223–33.

Miller, K. G., Feigenson, M. D., Wright, J. D. & Clement, B. M. 1991. Miocene isotope reference section, deep sea drilling project site 608: an evaluation of isotope and biostratigraphic resolution. *Paleoceanography* **6**, 33–52.

Moore, T. A. 1960. *The Geology and Mineral Resources of the Astromeritis-Kormakiti Area*. Geological Survey Department of Cyprus, Memoir 6.

Necdet, M. & Anil, M. 2006. The geology and geochemistry of the gypsum deposits in Northern Cyprus. *Geosound (Yerbilimleri)* **48–49**, 11–49.

Okay, A. i., Zattin, M. & Cavazza, W. 2010. Apatite fission-track data for the Miocene Arabia-Eurasia collision. *Geology* **38**, 35–8.

Raffi, I., Mozzato, C., Fornaciari, E., Hilgen, F. J. & Rio, D. 2003. Late Miocene calcareous nannofossil biostratigraphy and astrobiochronology for the Mediterranean region. *Micropaleontology* **49**, 1–26.

Robertson, A. H. F., Parlak, O., Rizaoğlu, T, Ünlügenç, U., İnan, N., Tasli, K. & Ustaömer, T. 2007. Tectonic evolution of the South Tethyan ocean: evidence from the Eastern Taurus Mountains (Elazığ region, SE Turkey). In *Deformation of the Continental Crust: The Legacy of Mike Coward* (eds A. C. Ries, R. W. H. Butler & R. H. Graham), pp. 231–70. Geological Society of London, Special Publication no. 272.

Robertson, A. H. F., Tasli, K. & İnan, N. 2012. Evidence from the Kyrenia Range, Cyprus, of the northerly active margin of the Southern Neotethys during Late Cretaceous-Early Cenozoic time. *Geological Magazine* **149**, 264–90.

Robertson, A. H. F., Ünlügenç, U., İnan, N., Tasli, K. 2004. The Misis–Andırın Complex: a Mid-Tertiary melange related to late-stage subduction of the Southern Neotethys in S Turkey. *Journal of Asian Earth Sciences* **22**, 413–53.

Robertson, A. H. F. & Woodcock, N. H. 1986. The role of the Kyrenia Range lineament, Cyprus, in the geological evolution of the Eastern Mediterranean area. In *Major Crustal Lineaments and Their Influence on the Geological History of Continental Lithosphere* (eds H. G. Reading, J. Watterson & S. H. White). *Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences* **317**, 141–77.

Wade, B. S., Pearson, P. N., Berggren, W. A. & Pälike, H. 2011. Review and revision of Cenozoic tropical planktic foraminiferal biostratigraphy and calibration to the geomagnetic polarity and astronomical time scale. *Earth Science Review* **104**, 111–42.

Weiler, Y. 1969. The Miocene Kythrea Flysch Basin. In *Cyprus. Committee of Mediterranean Neogene Stratigraphy, Proceedings IV Session, Bologna. Giornale di Geologia, Série 2* **XXXV**, fasc. IV, 213–29.

Weiler, Y. 1970. Mode of occurrence of pelites in the Kythrea Flysch Basin (Cyprus). *Journal of Sedimentary Petrology* **40**, 1255–61.

Yetiş, C., Kelling, G., Gökçen, S. L. & Baroz, F. 1995. A revised stratigraphic framework for later Cenozoic sequences in the northeastern Mediterranean region. *International Journal of Earth Sciences* **84**, 794–812.